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# FEASIBILITY STUDY OF A 270V DC FLAT CABLE AIRCRAFT ELECTRICAL POWER DISTRIBUTION SYSTEM


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This report includes a preliminary flat power cable design guide which has been written in a stand alone format. There is also a wire and connector supplier's proprietary supplement which is accessible only to authorized personnel of NADC or the Boeing Company.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Flat Conductor Power Cable, Stacked Conductors, Current Carrying Capacity, Voltage Drop, Weight Reduction, 270V DC, Electromagnetic Effects, Composite Airframes, Manufacturing Methods, Feasibility, Harness Design

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents the efforts of a one man-year feasibility study to evaluate the usage of flat conductors in place of conventional round wires for a 270 volt direct current aircraft power distribution system.

This study consisted of designing electrically equivalent power distribution harnesses in flat conductor configurations for a currently operational military aircraft. Harness designs were established for installation in →

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aircraft airframes which are: (1) All metal, or (2) All composite, or (3) a mixture of both.

Flat cables have greater surface areas for heat transfer allowing higher current densities and therefore lighter weight conductors, than with round wires. Flat cables are less susceptible to electromagnetic effects. However, these positive factors are partially offset by installation and maintenance difficulties. This study concludes that the extent of these difficulties can be adequately limited with appropriate modifications to present installation and maintenance practices.

A comparative analysis of the flat and the round conductor power distribution harnesses was made for weight, cost, maintenance and reliability. The knowledge gained from the design and comparative analysis phases was used to generate design criteria for flat power cable harnesses and to identify and prioritize flat cable harness components and associated production tooling which require development.

The comparative analysis demonstrated that state-of-the-art flat cable has a 30% weight advantage over round wires, with equal cost, maintenance and reliability parameters. It appears that the weight savings could be enhanced to between 40% and 50% with a relatively small investment in component development. The net effect on a military aircraft would be a considerable savings in distribution harness weight which can be translated into savings in fuel cost or an extension in mission range.

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# 1.0 INTRODUCTION

## 1.1 Summary and Conclusions

o Military/aerospace usage of flat power cables is limited at this time.

o Optimized flat cables have up to a 50% weight advantage over round wires, due to higher tolerable current densities.

o Installation of flat cables would require a combination of bend preforming during harness assembly and final forming during installation.

o Due to the stiffness of flat power cable and the permanent bends performed during installation, extraction of a harness for maintenance tasks would be difficult. However, the occurence of damage or failures which could not be repaired while the harness is in place would be low. It would be most cost effective to cut an in-place non-repairable harness out and replace it with a new one.

o The sum of life cycle costs for procurement, harness buildup, installation, and maintenance are equal when comparing flat cables to round wires. The net effect of flat cable usage would be a savings in fuel costs or an extension in mission range, due to the lighter weight harnesses.

o Flat cable shielding requirements could not be determined within the

constraints of this study. It is expected that flat cables would have an advantage over round wires where EMI, EMP, EMC, and lightning considerations are involved. This is a question that should be addressed in future studies.

## 1.2 Background

Weight reduction is a constant goal in aircraft. Recent innovations to achieve reduced weight in aircraft airframes have included the use of structural composite materials in ever increasing quantities and the use of large scale integrated (LSI) digital solid-state avionics equipment.

The use of composite materials in aircraft affects the electrical system in two ways: (a) the higher electrical resistance affects or precludes the use of the airframe for electrical ground return, and (b) composite structures do not provide the shielding from electromagnetic effects (EME) that metal airframes provide.

The use of LSI digital avionics equipment places new demands on electrical power supplies to remain at constant, transient-free levels. A sudden surge or momentary drop in digital navigation equipment supply voltage can cause undesired memory or register changes as well as possibly damaging the LSI circuits.

The addition of a separate wire for ground return and the additional shielding requirements not provided by composite airframes would result in an increase in power distribution system weight of 30 to 50 percent.

To effectively deal with the problems mentioned above and avoid the weight penalties that would be imposed by conventional power distribution techniques, an alternative conductor geometry has been proposed. The configuration consists of two, wide, thin, copper strips placed back-to-back

and separated by a thin dielectric material.

This configuration offers several advantages over conventional round wires. For conductors with the same cross section, the flat conductor has a greater surface area for cooling, hence, a greater current density is possible with the same tolerable insulation temperature. This reduces the weight of copper required in a given harness.

Another advantage of the flat, closely space conductors are decreased inductance, increased capacitance, and a decreased electromagnetic field emitted by the harness. These parameters reduce problems of electromagnetic fields being coupled to a harness and reduce compatibility problems with nearby wiring and electrical equipment.

The flat power cable concept presents unique and challenging problems with harness build-up, airframe installation, maintenance, and termination. Whether flat power cables have sufficient advantages to overcome the problems associated with the new technology is a question that this report will answer to the best level possible.

## 1.3 Program Approach

To evaluate the extent of positive and negative factors involved with flat power cables, a comparative analysis approach was used.

An operational fixed wing aircraft was selected from present military inventory. Replacement harnesses were designed for selected runs based on 270V DC equivalent power ratings in both flat and round configurations, assuming (a) an all metal aircraft, (b) an all-composite aircraft, (c) a mixture of both.

The replacement designs were then analyzed for (a) harness weight, (b) life cycle costs (procurement, build-up, installation, and maintenance), (c) reliability, and (d) maintenance considerations (other than cost).

The knowledge gained from the harness design and comparative analysis was used to generate a flat cable harness design, manufacturing build-up, and airframe installation guide, as well as to identify harness components and production tooling required for successful flat cable utilization.

Concurrent with the initial phases of the program, a literature search and a wire and connector industry survey were conducted to determine the state-of-the-art with flat power cable usage in aircraft,missiles, launch vehicles, spacecraft, or ground systems.

The general program flow can be seen in Figure 1.2.1.

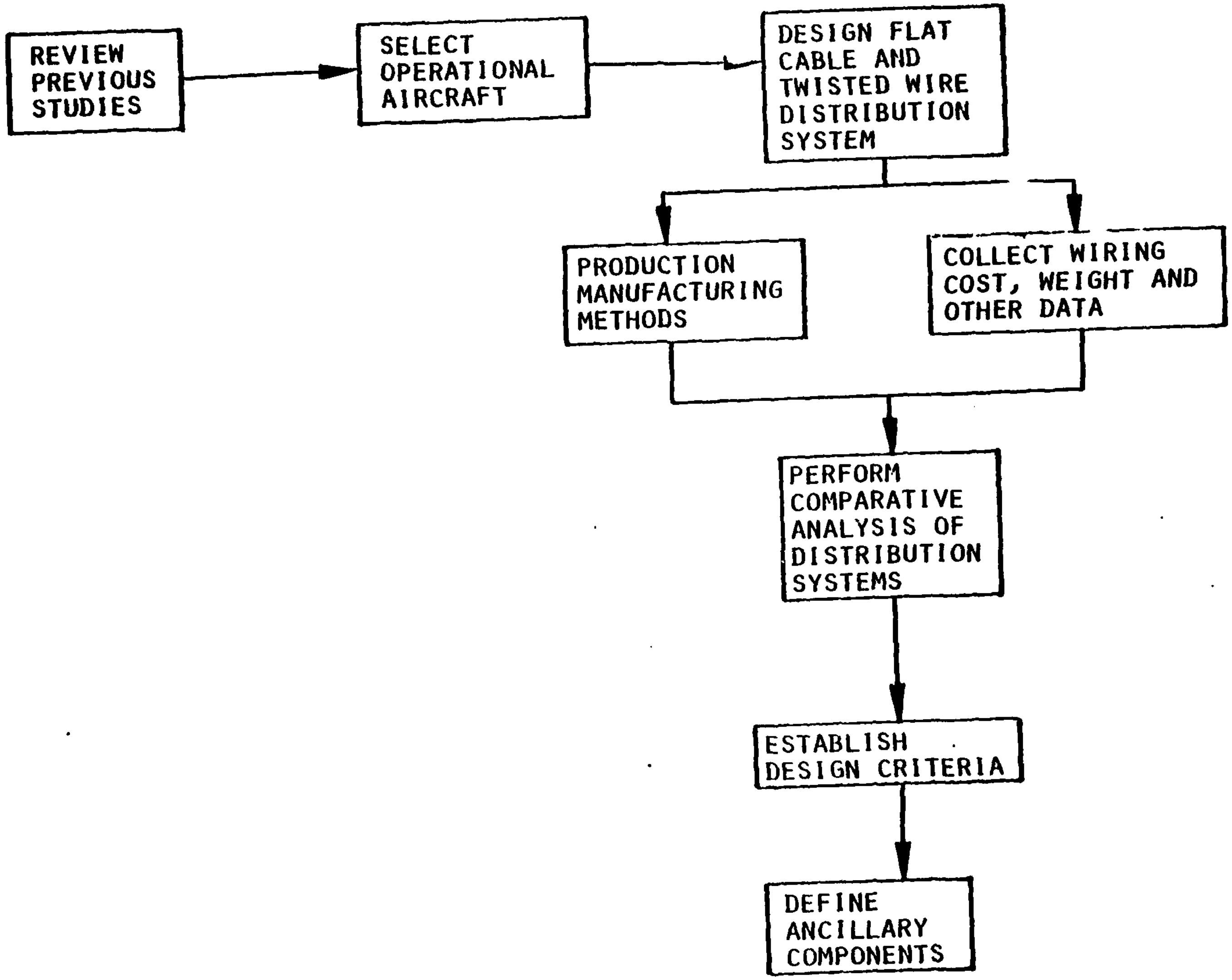



FIGURE 1.2.1 GENERAL PROGRAM FLOW DIAGRAM

## 2.0 FLAT CABLE STATE-OF-THE-ART—LITERATURE SEARCH AND WIRE AND CONNECTOR INDUSTRY SURVEY

### 2.1 Literature Search

With the aid of Boeing's computerized literature search of major technical data banks, a list of recent documents dealing with flat conductor power cable was generated. A list of these documents can be seen in the Bibliography (Appendix A).

Copies of the documents were reviewed and it was found that a large majority of the documents were focused towards the use of multi-conductor signal-type ribbon cable, rather than the large gauge flat power cables under consideration in this study. This fact is useful since the solutions to problems of harness support and routing for ribbon cable are applicable to flat power cable.

## 2.2 Wire and Connector Industry Survey

A variety of means was used to determine what flat cable components are currently available commercially or are in the development stages. The bulk of the survey was performed by correspondence sent to wire and/ or connector manufacturers with previous aerospace and/or flat cable involvements. The remaining information was collected by reviewing information currently on file or informal contacts with assorted industry personnel. The results of this study's survey most probably represents the average condition of state-of-the-art commercial flat cable components.

Of the fifty manufacturers contacted, roughly 20% of the responses were positive to some extent. Most of the potential harness components which are currently available are designed for ground systems. These components could most probably be developed to the rough service and high reliability requirements of airborne equipment with a moderate amount of redesign.

A listing of these present flat cable components can be reviewed in the supplement to this report. The data in the supplement have been classified as proprietary at the request of some of the respondents to the survey. Access to the supplement is restricted to authorized personnel of The Boeing Company and the Naval Air Development Center.

# 3.0 FLAT CABLE AND ROUND WIRE EXAMPLE HARNESS DESIGN AND COMPARATIVE ANALYSIS

## 3.1 Example Airframe Selection

The airframe selected for study was the E-3A, which is currently in full production and operation. The adaptation of the Boeing 707 jetliner to the current configuration of the E-3A started approximately 15 years ago, and the 707 has been in service for more than 20 years. Well established wiring weight, electrical parameter, manufacturing and maintenance data are readily available for the E-3A.

In the adaptation of the 707 to the E-3A configuration, the electrical generating capacity was increased by a factor of 3. This demonstrates the complexity of power distribution in a sophisticated military surveillance aircraft. Hence, the E-3A offered a wide range of power cables to select the example harnesses from.

The E-3A electrical system is 115/200 volt, 3-phase, Y-connected, 400 hertz power, which is also the system in use on many military aircraft that is being considered for replacement with 270 volts D.C.

## 3.2 Example Harness Selection

The E-3A contains approximately 1100 power distribution harnesses to choose from. The following factors were included in the selection of harnesses for the study:

(1) Several harnesses were selected to provide a suitable range of current requirements (2.0 to 300.0 amps).

(2) Inclusion of wire routing in tight quarters and frequent course changes were desireable factors for study of installation difficulties.

(3) Both pressurized and unpressurized areas were included.

(4) High and low temperature environments were included.

(5)conditions where high vibration and length changes due to airframe stress or thermal expansion/contraction were included.

After evaluation of candidate harnesses for the above factors, the existing runs given in Table 3.2.1 were chosen for study. Table 3.2.2 gives the required harness ampacities for 270V DC based on equivalent power ratings of the 115/200V AC system.

TABLE 3.2.1

Descriptive Parameters of Example
Harnesses Selected for Study
(All ampacities are 115/200 volt, 3 phase, alternating current values)

| Harness | Nominal Load in Amps | Harness Run |
|---|---|---|
| 1. W0294 | 200.0 (high ampacity)<br>Wire Gauge - #4 AWG* | From generator #1 engine to pylon firewall (F/W) |
| 2. W0322 | 200.0<br>Combination of AL & CU<br>Wire Gauge - #4 AWG*<br>Wire Gauge - #2 AWG (Alum.) | From Pylon F/W to Generator Control Breaker (GCB) E15 Rack (left side of aircraft) |
| 3. W0844 | 60.0 (medium ampacity)<br>Wire Gauge - #6 AWG* | From control unit in E16 rack (right side of aircraft) through pressure seal to liquid cooling system pump on left wheel well bulkhead |
| 4.W2343 | 12.7 (Low-1 ampacity)<br>Wire Gauge - #8 AWG* | From CB panel to communication cabinet |
| 5.W0708 | 2.5 (Low-2 ampacity)<br>Wire Gauge - #18 AWG* | From CB panel P61-1 to fuel control module M708 in E16 rack |

*All wire copper, unless otherwise noted.

TABLE 3.2.2

EXAMPLE HARNESS AMPACITIES FOR EQUIVALENCE OF 270V DC
TO 115/200 VAC, 3Ø

| Power | | Harness Designation | 115/200 VAC Load Current, Amps Per Phase | 270V DC Load Currents,* Amps |
|---|---|---|---|---|
| Load | Ampacity Range | | | |
| 75 KVA | High (101-300A) | WØ294, WØ322 | 216.5 | 277.8 |
| 20 KVA | Medium (31-100A) | WØ844 | 60.0 | 74.0 |
| 4.5 KVA | Low-1 (11-30A) | W2343 | 13.0 | 16.7 |
| 1.0 KVA | Low-2 (2-10A) | WØ708 | 2.5 | 3.7 |

*Based on Equivalent Power at Power Factor = 1.0

$$I_{LDC} = \frac{P_{DC}}{270}$$

$$I_{LAC} = \frac{P_{AC}}{\sqrt{3} \times 200}$$

### 3.3 Replacement Harness Designs - Considerations Common to Both Flat and Round Conductors.

#### 3.3.1 Airframe Types - Composite, Metal, or Mixtures

The three airframe types under consideration for this study are (1) all metal, (2) all composite, (3) mixtures of both metal and composite. What was done was to consider that our selected aircraft (the E-3A) was so constructed for each of the three types.

It was soon realized that, lacking specific structural details, the metal/composite airframe was too vague to allow specific harness design and analysis. For example, if the mixture consisted of a composite skin with occasional metal structural members, electrical resistance through the hull would probably be too high to permit structural current return, and negligible shielding would be provided from electromagnetic effects (EME). In this case, the metal/composite airframe would essentially resemble a 100% composite airframe from a harness design standpoint. On the other hand, if the metal/composite airframe had a complete outer metal skin with composite structural members, the metal skin could be used for current return and shielding would be provided by the skin. In this case, the airframe would most closely resemble the all-metal airframe. Therefore, the mixed material airframe was considered to behave like the material of the outer skin, and no further consideration was necessary exclusively for it.

### 3.3.1.1 Admittance of External Electromagnetic Fields in Metal or Composite Airframes

A. All Metal Air Frame

The air frame effectively shields the wiring from exposure to electromagnetic effects (EME), provided there are no openings in the skin, like landing gear doors, cockpit windows and openings around access doors and attachments of flight control surfaces. During the most probable time of exposure to EME, during flight, most openings would be closed.

B. All Composite Air Frame

Graphite epoxy skin and structure by itself offers no shielding to the cable runs or other electrical components. It is necessary to add protection to the wiring itself and solid state circuits to prevent EME interference or damage.

The electromagnetic effects mentioned above include electromagnetic interference (EMI) and nearby lightning strikes, but not direct lightning strokes. Lightning presents an additional threat to composite structures in that direct lightning strokes of sufficient magnitude can rupture composite skin and seek out internal metallic components (such as wiring).

In the case of composite airframes, lightning protection must be provided by (1) selecting routing paths away from high threat areas, (2) using surge arrestors, (3) providing sufficient electrical isolation of metal components (structural members, equipment cases, wiring, etc.) in high threat areas, (4)

providing low impedance preferred paths for lightning. For the purposes of design of the replacement harnesses in this study, it has been assumed that sufficent lightning protection has been added by other means and no lightning protection is necessary as a part of the harness except for the provision of maintaining ground conductor isolation from the partially conductive composite structure in high lightning threat areas. Figures 3.3.1 and 3.3.2 serve to illustrate the definition of lightning threat level areas. Zone 3 in figure 3.3.2 will be referred to as a low EM threat area for the remainder of this report.

In the low EM threat areas of composite airframes, it was considered necessary to provide an electrical connection of ground conductors, shields, and equipment metal cases to the airframe to prevent a personnel hazard due to a possible static charge buildup between the airframe and exposed circuit grounds.

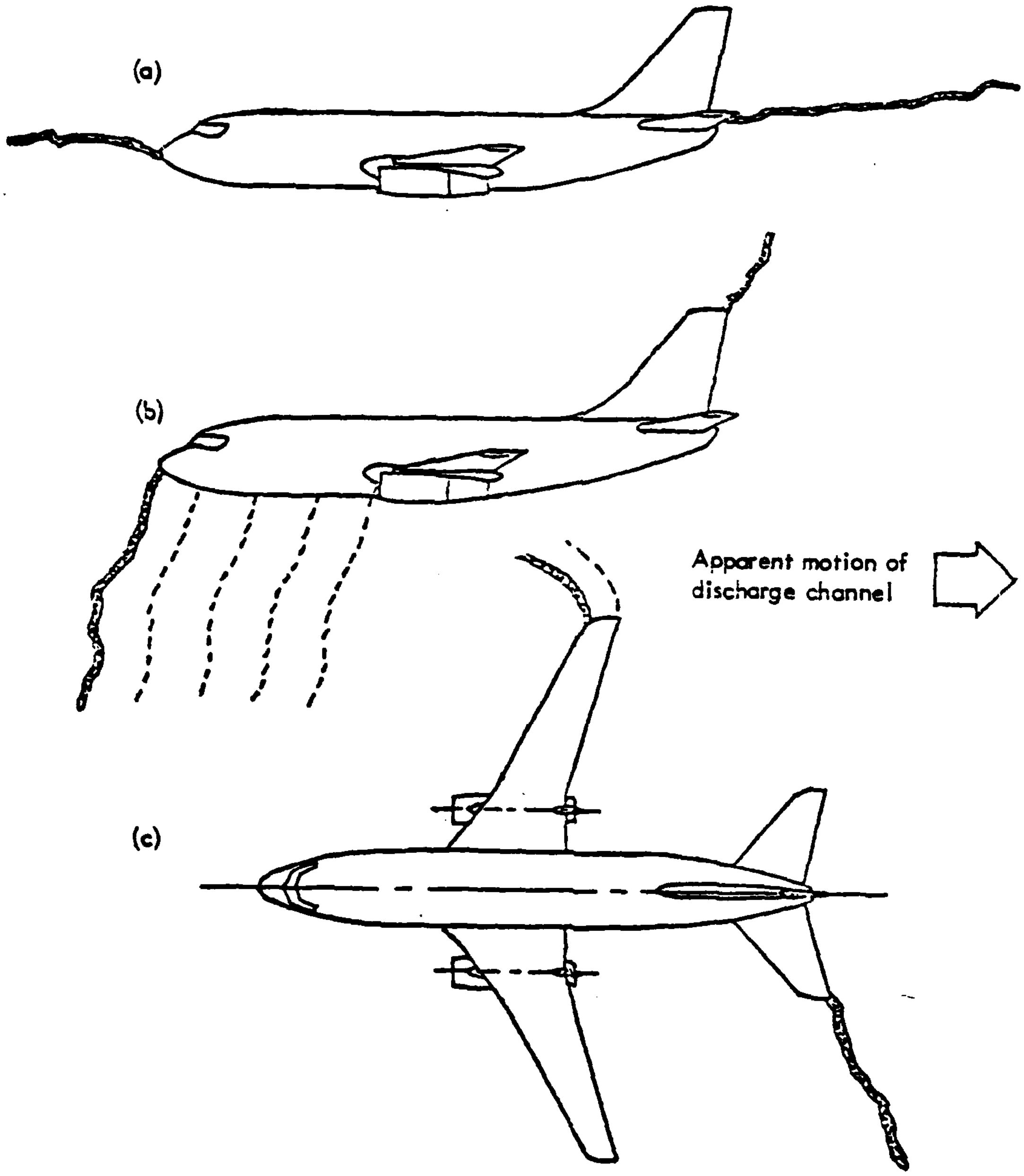



**Figure 3.3.1 : Sketch Illustrating Swept Stroke Phenomenon**

ZONE 1 Surfaces for which there is a high probability of direct stroke attachment.

ZONE 2 Surfaces for which there is a probability of stroke being swept rearward from a Zone 1 point of direct stroke attachment.

ZONE 3 Surfaces for which there is a low probability of either direct or swept stroke attachment.

**Note:** If leading or trailing edge devices are extended, they may also be categorized as Zone 1. An extended landing gear is in Zone 1.

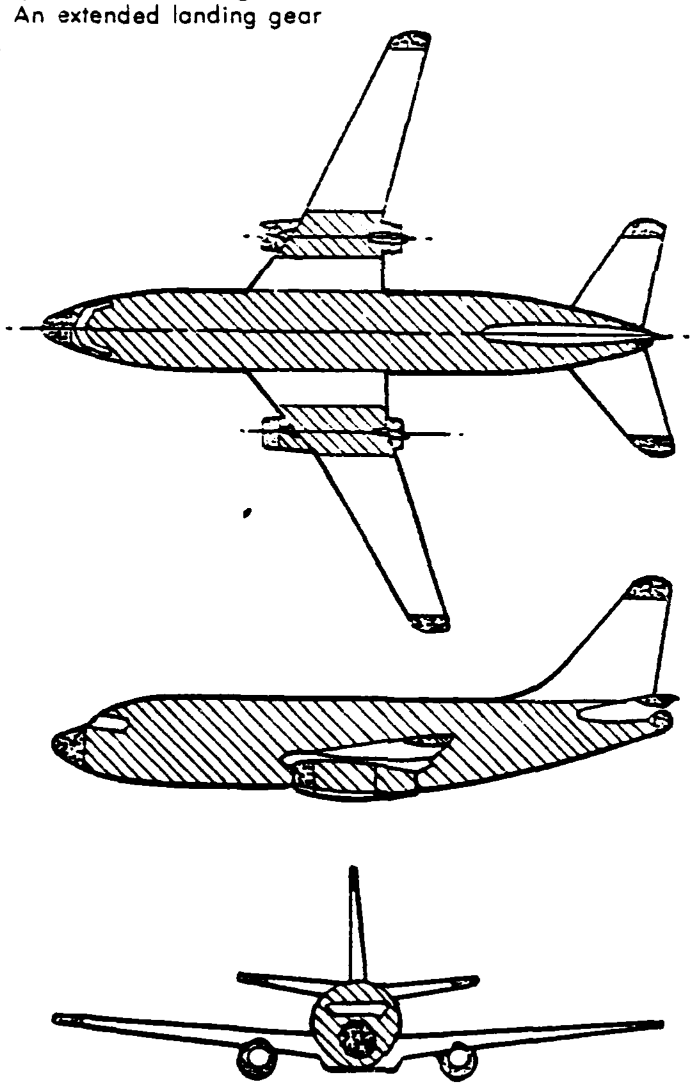


**Figure 3.3.2 : Lightning Strike Zones For Typical Subsonic Jet**

### 3.3.2 Conductor Material Selection - Aluminum Versus Copper Conductor

At first glance, the use of aluminum conductors seems quite attractive from a weight savings standpoint. The conductivity of aluminum is only 63% of the conductivity of copper. However, the density of aluminum is 30% that of copper. This means that for given conditions of current, temperature and voltage drop, an aluminum conductor must have 59% greater cross-section than a copper conductor, but the aluminum conductor would weigh 52% less.

There are other considerations which diminish the benefits of using aluminum:

a. For the equivalent aluminum conductor above, the increase in cross section results in an increase in total insulation, which decreases the weight savings.

b. The mechanical strength of aluminum creates problems when an attempt is made to utilize it in small gauge sizes. Boeing does not recommend using aluminum for round wires with cross-section below #6 AWG as a general rule.

c. It is usually desired to utilize both copper and aluminum wires in a given structure. This means that, at some point, the two must make electrical contact. Being dissimilar metals, galvanic corrosion and differential thermal expansion are problems. Splice fittings are available that employ chemical inhibitors; however, they present a weight and space penalty over regular fittings.

In addition to these general considerations, there are some specific considerations when considering aluminum versus copper in flat conductor cable.

d. The requirements for greater cross-section when using aluminum results in a larger surface area for heat transfer. This change does not significantly affect temperature rise in the case of round wire, but it is significant with flat cable. Thus, the weight of aluminum in flat cable is reduced even further over the weight savings of aluminum versus copper in round conductors.

e. The mechanical strength problems with aluminum become even more critical due to the thinness of flat conductor. Aluminum has less ductility than copper. Breakage would become a problem in areas of tight routing, frequent flexing and vibration.

In summary, aluminum conductors will be used in power runs where routing, bends and flexing are infrequent and vibration levels would be low.

For other conditions, copper will be used due to the greater ductility and vibration resistance.

### 3.3.3 Conductor Sizing Procedure - General Considerations

In sizing aircraft wiring, it is desireable to use the smallest wires possible without exceeding the temperature limits of the wire or the

allowable voltage drop of the circuit. In the E-3A, the main feeders from the generators to the distribution rack are not regulated for voltage. The conductors are sized for maximum allowable temperature according to steady state current or expected transient overload, whichever has the greatest temperature rise. Generator excitation can be adjusted to offset conductor voltage drop. For our replacement designs, there is no transient overload associated with the remaining system, as there is no remaining system defined. Conductors were sized for steady state maximum currents and the overload capacity for a period of 40 milliseconds is given (40 milliseconds is the present response time of DC solid-state transient suppressors). 'Downstream' from the point of regulation the circuit voltage drop became a significant consideration for conductor sizing. Conductor voltage drop is usually specified as a percentage of the supply voltage, approximately 3% by present IEEE standards. This amounts to 1.0 volt for a 28V system, 4.0V for a 120V system, or 8.0V for a 270V system. This 3% rule-of-thumb is only a guideline for general design purpose. In practice, allowable voltage drop will vary over a considerable range, depending on the power supply voltage variation tolerance at the equipment terminals. For the selected harnesses the allowable voltage drop was specified to be equal to that allowed in the present 120 VAC harnesses.

For this study's designs, single positive leads and structural ground returns were used in metal airframes, while positive leads and ground return conductors were used in composite airframes (except for harness W2343, to be discussed later in this section). Metal airframe ground return paths usually have sufficient cross-section to result in negligible voltage drop; hence, allowable voltage drop is consumed by the single positive lead. For a two

conductor DC system, each conductor will consume half of the total allowable voltage drop.

This fact suggests an area of investigation for composite airframe electrical equipment designers. The use of present power supply voltage drop guidelines (3%) will result in increased conductor weight penalties due to voltage drop frequently being the controlling parameter in two wire system wire sizing. By increasing the recommended voltage drop (up to around 4 to 6% maximum) between the source and the load, this weight penalty can be avoided.

As mentioned earlier in this section, harness W2343 has been designed as a two wire system in both metal and composite airframes. This is due to two factors in the harness requirements: (1) the harness is unusually long (90 feet) compared to an average (approximately 50 feet) for the E-3A, (2) the using equipment has unusually stringent requirements for a "quiet" (essentially transient-free), constant-level power supply. The use of structure for the current return will therefore not be used for this harness.

### 3.3.4 Summary of Harness Requirements

W0294: From #1 generator to firewall (W0322)
Ampacity: 277.8A (@ 270V DC)
Ambient Temperature Range: $-40^{o}C$ to $+215^{o}C$
Allowable Voltage Drop: None Specified
Remarks: Frequent course deviations around engine

W0322: From firewall (W0294) to E-15 distribution rack
Ampacity: 277.8A (@ 270V DC)
Ambient Temperature Range: $-40^{o}C$ to $+105^{o}C$
Allowable Voltage Drop: None Specified
Remarks: Intermittent exposure to exterior requires abrasion sleeving; because of connector contact size limitation, parallel circuits are required through firewall.

W0844: From E-16 distribution rack to LCS pump in left wheel well
Ampacity: 74.0A (@ 270V DC)
Ambient Temperature Range: $-40^{o}C$ to $+105^{o}C$
Allowable Voltage Drop: 6.0V
Remarks: Abrasion sleeving required in wheel well area

W2343: From FWD CB panel to communications cabinet
Ampacity: 16.7A (@ 270V DC)
Ambient Temperature Range: $0^{o}C$ to $+37^{o}C$
Allowable Voltage Drop: 2.0V
Remarks: Structural ground return unacceptable in metal airframes

W0708: From M708 on E16 rack to P61-1 CB panel
Ampacity: 3.7A (@ 270V DC)
Ambient Temperature range: $0^{o}C$ to $+37^{o}C$
Allowable Voltage Drop: 1.0V
Remarks: None

### 3.4 Round Wire Replacement Harness Designs

The round wire replacement harnesses were designed by conventional methods, using sources such as MIL-W-5088H, MIL-W-25038, Boeing Documents D-7900, Boeing Design Standards and Materiels Specifications. As mentioned previously, one positive lead with structural ground return was used in metal airframes, and two-wire harnesses were used in composite airframes.

The requirements for shielding are dependent on a large number of factors: (1) The type and level of EM threat, (2) the type of equipment and its' associated sensitivity to power supply transients , (3) use of optional methods for EM threat control.

Lacking specific information on the airframe and the 270V DC electrical system, much generalizing and assuming was necessary. It was assumed that the metal airframe was continuous and provided all necessary shielding except in two areas: (1) the generator feeders (W322) in the leading edges of the wing are exposed during extension of the leading edge slats as well as through apertures in rivetted areas of the wing skin, (2) harnesses to the LCS pump (W844) in the left wheel well would be exposed when the landing gear is extended or through apertures in the wheel well doors. Harnesses in these areas require both electromagnetic shielding and abrasion resistant sleeving.

It was assumed that harnesses in composite airframes would categorically require 100% shielding, although shielding requirements would depend on the three factors mentioned earlier in this section and its use could probably be

eliminated in some cases.

Where round wire shielding was required, conventional braided wire shielding (Federal Specification QQ-B-575) was used. This would be used in metal airframes, but other methods might be used for shielding round wire in composite airframes, such as metal-lined raceways. As the design variables for weight and cost would be distributed among several harnesses in a metal lined raceway, braided wire shielding was used on round wire harnesses in composite airframes only to be representative of shielding weight and cost. It should not be concluded from this design study that braided wire shielding is the only acceptable method for shielding of round wires in composite airframes.

In addition to the shielding requirements assumptions, it was assumed that source or load equipment cases in high EM threat areas possess sufficient electrical isolation from composite skin/structures. Shield terminations were designed to remain electrically isolated from composite skin/structures except in low EM threat areas where a shield termination to structure is provided. Shield terminations are $360^{\circ}$ at a connector backshell or terminal interface with low impedance pigtails to structural ground, where provided. Connection of shields to circuit ground were assumed to be only in low EM threat areas.

Schematic diagrams of the replacement round wire harnesses in composite aircraft are given in Figures 3.4.1 through 3.4.4. The schematics for metal airframes are given in Figures 3.4.5 through 3.4.8.

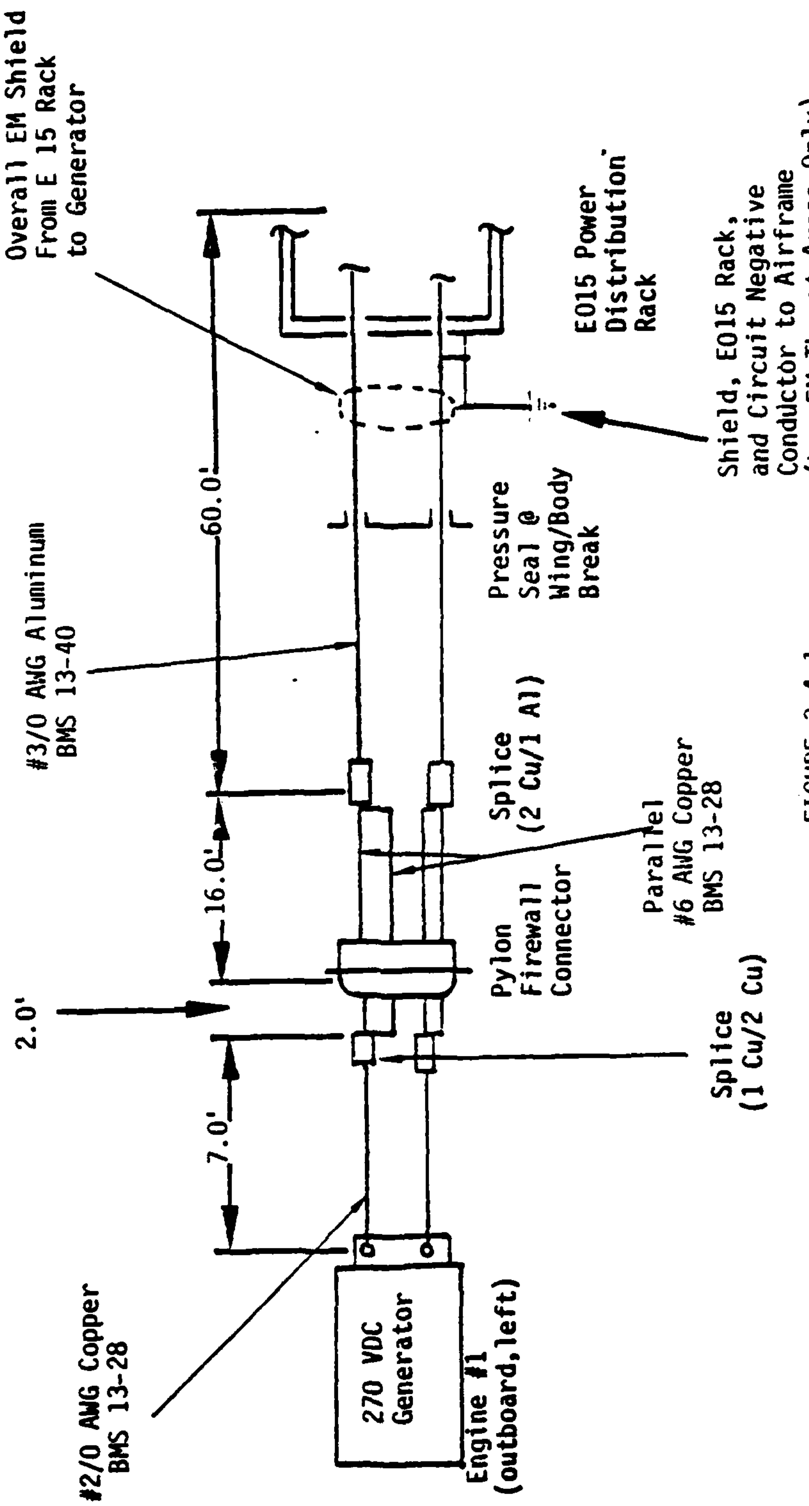



FIGURE 3.4.1

HIGH AMPACITY (W0294 + W0322)
ROUND WIRE REPLACEMENT HARNESSES
IN COMPOSITE AIRFRAMES
(SCHEMATIC DIAGRAM)

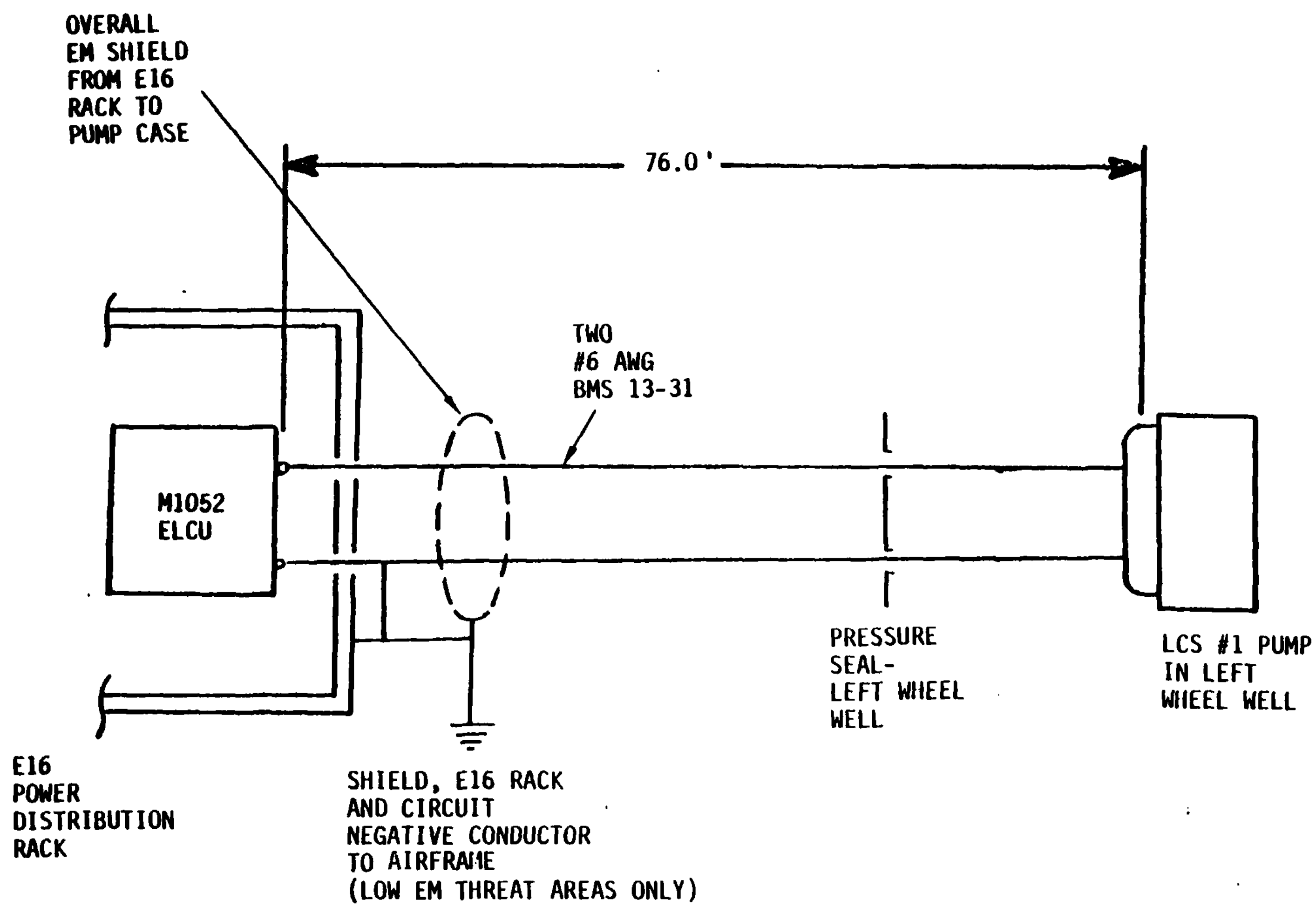



FIGURE 3.4.2
MEDIUM AMPACITY (W0844) ROUND WIRE
REPLACEMENT HARNESS IN COMPOSITE AIRFRAMES
(SCHEMATIC DIAGRAM)

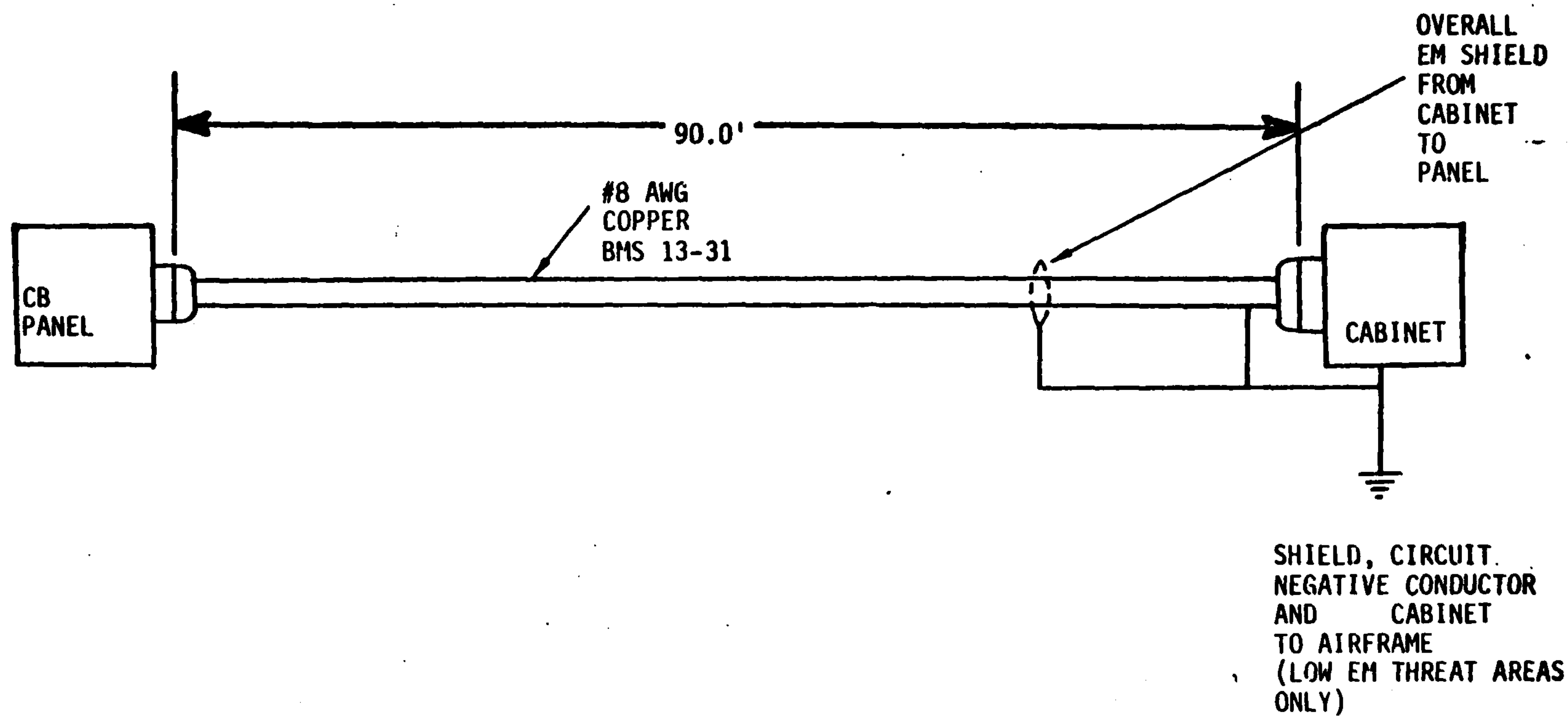



FIGURE 3.4.3

LOW-1 AMPACITY (W2343) ROUND WIRE
REPLACEMENT HARNESS IN COMPOSITE AIRFRAMES
(SCHEMATIC DIAGRAM)

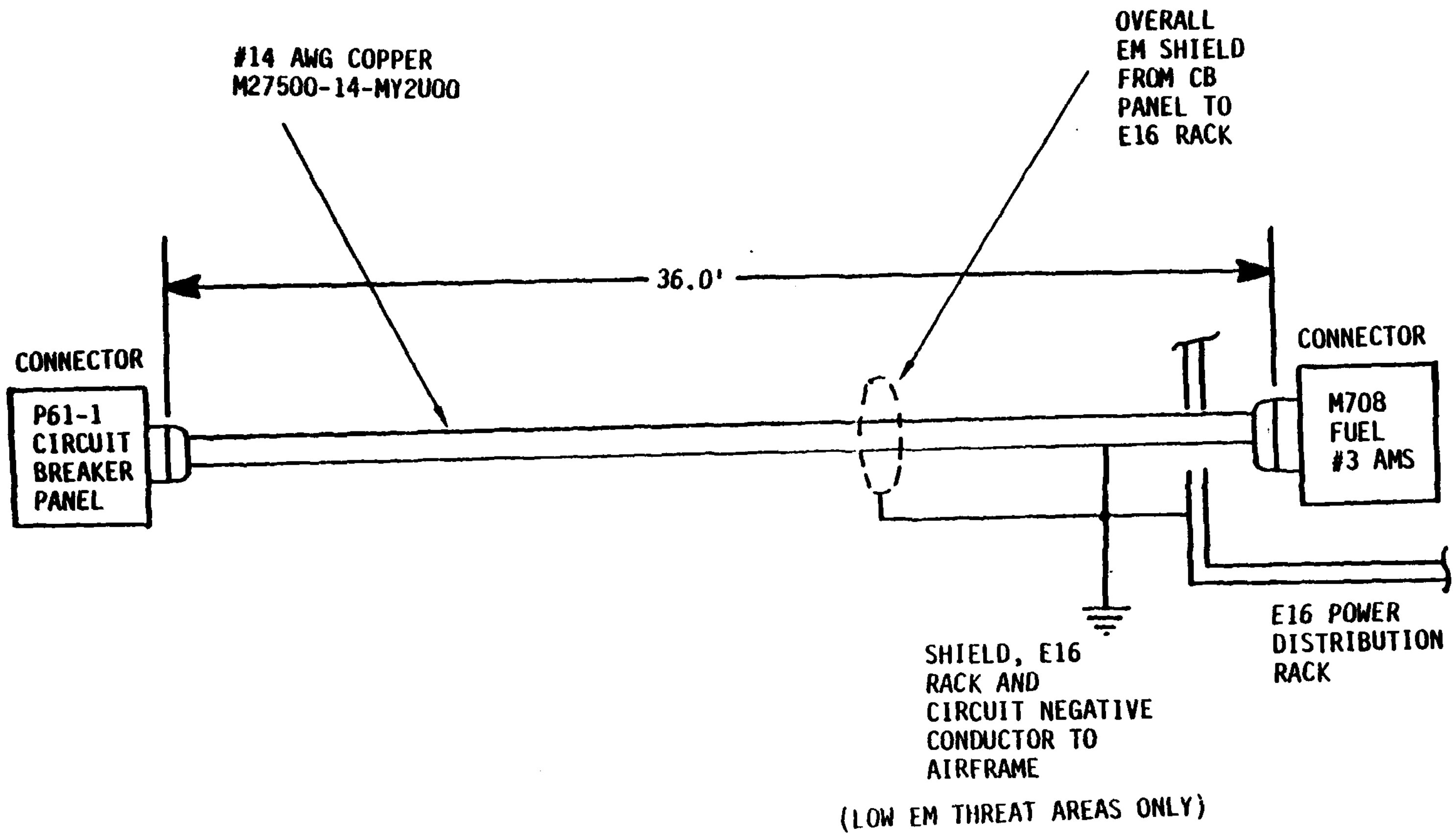



FIGURE 3.4.4
LOW-2 AMPACITY (W0708)
ROUND WIRE REPLACEMENT HARNESS
IN COMPOSITE AIRFRAMES
(SCHEMATIC DIAGRAM)

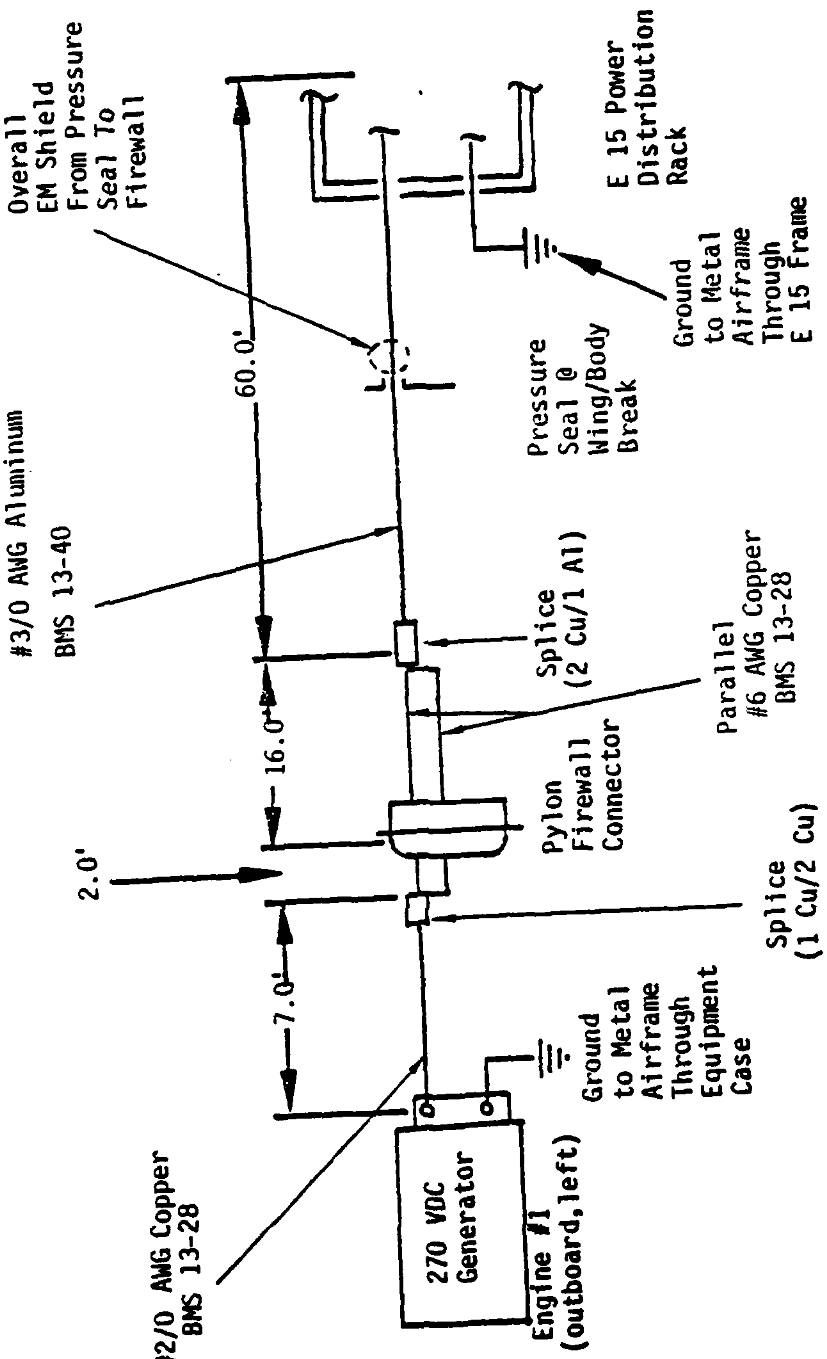



FIGURE 3.4.5

HIGH AMPACITY (W0294 + W0322)
ROUND WIRE REPLACEMENT HARNESSES
IN METAL AIRFRAMES
(SCHEMATIC DIAGRAM)

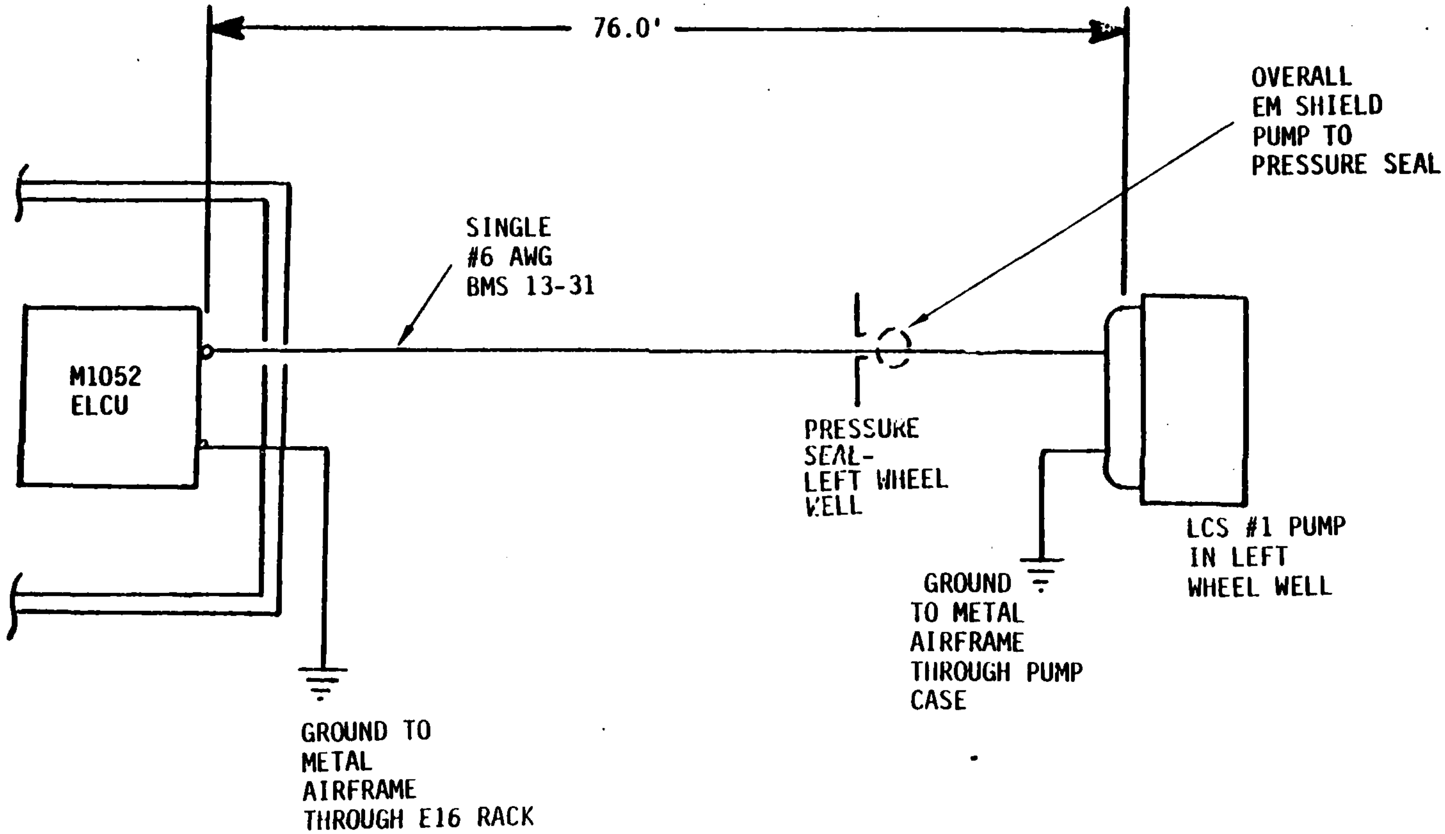



FIGURE 3.4.6

MEDIUM AMPACITY (W0844)
ROUND WIRE REPLACEMENT HARNESS
IN METAL AIRFRAME
(SCHEMATIC DIAGRAM)

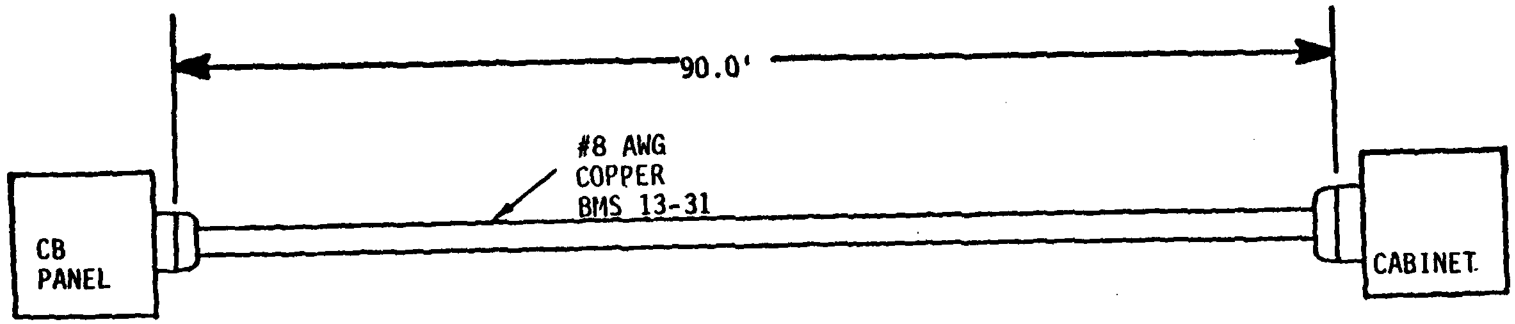



FIGURE 3.4.7

LOW-1 AMPACITY (W2343) ROUND WIRE
REPLACEMENT HARNESS IN METAL AIRFRAMES
(SCHEMATIC DIAGRAM)

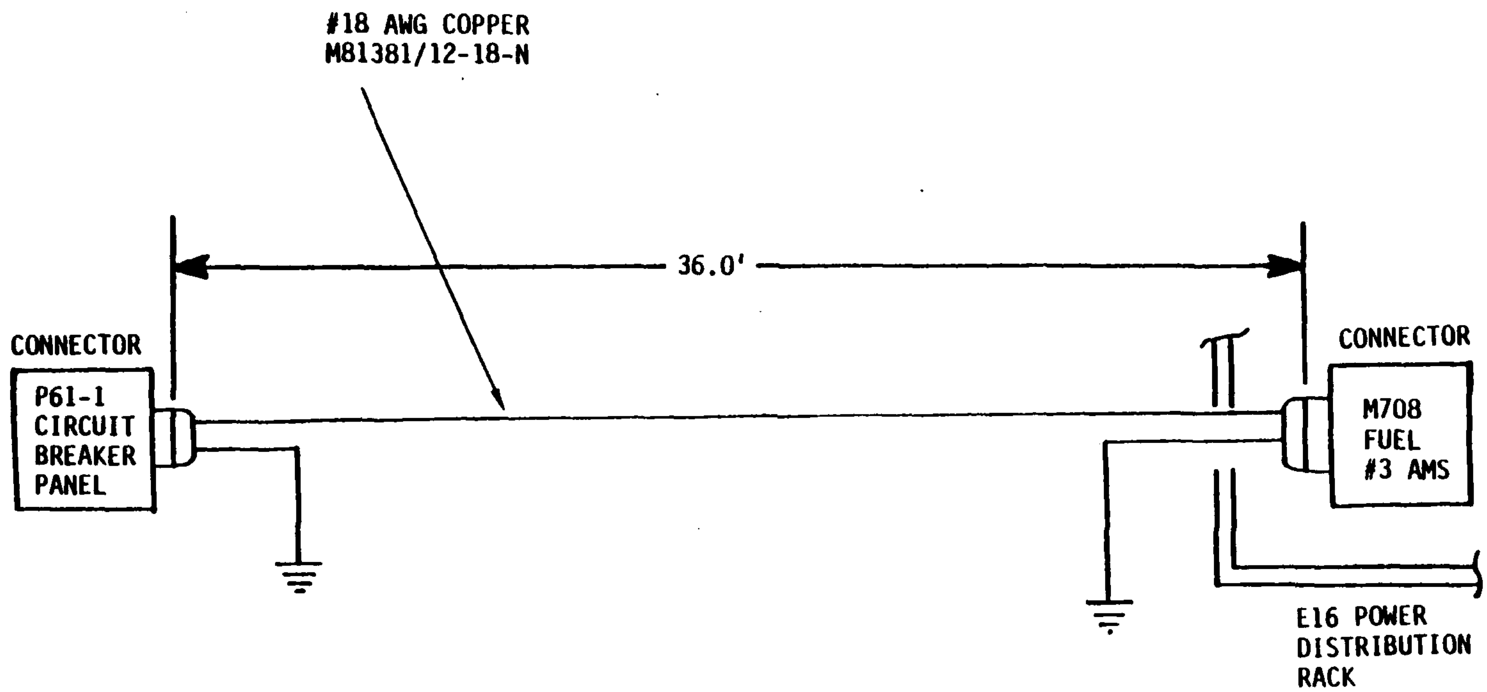



FIGURE 3.4.8
LOW-2 AMPACITY (W0708)
ROUND WIRE REPLACEMENT HARNESS
IN METAL AIRFRAMES
(SCHEMATIC DIAGRAM)

## 3.5 Flat Cable Replacement Harness Designs

### 3.5.1 Flat Cable Conductor Sizing

The sizing of flat conductor replacement harnesses followed the criteria given in Section 3.3.3 for conductor temperature and allowable circuit voltage drop.

The conductor temperature is a direct function of the square of the current flowing in the conductor. A steady state energy balance on a single insulated conductor free standing in air yields the equation:

$$(I^2)(R)(K) = (H)(A)(\Delta T)$$

where

I = Load Current, Amps

R = Conductor Electrical Resistance, OHMS/FT

K = A Conversion Constant, BTUS/WATT

H = Heat Transfer Coefficient, BTU/HR $FT^2F$

A = Surface Area of Conductor, $FT^2/FT$

$\Delta T$ = Temperature Difference Between Conductor and Ambient, $^{\circ}F$

(The development of this equation is given in Appendix B)

| Round Wire AWG # | X-Section In$^2$ | W/T = 150 Width In. | W/T = 150 Thickness In. | W/T = 200 Width In. | W/T = 200 Thickness In. |
|---|---|---|---|---|---|
| 30 | .0000880 | 0.115 | .000766 | 0.133 | .000663 |
| 28 | .000137 | 0.143 | .000956 | 0.166 | .000828 |
| 26 | .000239 | 0.189 | .00126 | 0.219 | .00109 |
| 24 | .000373 | 0.237 | .00158 | 0.273 | .00137 |
| 22 | .000592 | 0.298 | .00199 | 0.344 | .00172 |
| 20 | .000955 | 0.378 | .00252 | 0.437 | .00219 |
| 18 | .00149 | 0.473 | .00315 | 0.546 | .00273 |
| 16 | .00191 | 0.535 | .00357 | 0.618 | .00309 |
| 14 | .00301 | 0.672 | .00448 | 0.776 | .00388 |
| 12 | .00461 | 0.832 | .00554 | 0.960 | .00480 |
| 10 | .00735 | 1.050 | .00700 | 1.212 | .00606 |
| 8 | .0133 | 1.412 | .00942 | 1.631 | .00815 |
| 6 | .0211 | 1.779 | .01186 | 2.054 | .0103 |
| 4 | .0335 | 2.242 | .01494 | 2.588 | .0129 |
| 2 | .0522 | 2.798 | .01865 | 3.231 | .0162 |
| 1 | .0642 | 3.103 | .02069 | 3.583 | .0179 |
| 0 | .0821 | 3.509 | .02340 | 4.052 | .0203 |
| 2/0 | .104 | 3.950 | .02633 | 4.561 | .0228 |
| 3/0 | .131 | 4.433 | .02955 | 5.119 | .0256 |
| 4/0 | .166 | 4.990 | .03330 | 5.762 | .0288 |

TABLE 3.5.1.1

FLAT DIMENSIONS FOR EQUIVALENT CROSS SECTION
TO CONVENTIONAL SIZE ROUND WIRES

The heat transfer coefficient is most strongly a function of the mode of transfer, i.e., free convection, forced convection, conduction, and/or radiation. It is also a weaker function of the pressure and temperature-dependent physical properties of the transfer medium (air) and wire geometry (flat or round).

Dimensions for flat conductors with width-to-thickness ratios (W/T) of 150 and 200 were calculated based on equivalent metallic cross sections of military standard AWG round conductors. These dimensions can be seen in Table 3.5.1.1. Current capacities for the cables were calculated via a computer program for the variables:

Ambient temperatures -50, 150, 250, 350$^{\circ}$F

Conductor Temperature Rise - 50, 100, 150$^{\circ}$F

Altitude - 0 to 80,000 feet

Conductor Material - Copper or Aluminum

Development of the equations and the computer program can be seen in Appendix C.

The output of the computer program was used to construct graphical representations of the temperature rise of the conductors versus load current for the range of variables mentioned above. Aside from the expected increase in current capacity of flat cables due to an increase in surface area for heat transfer, an interesting phenomenon was noticed.

This phenomenon is the existence of a high ambient temperature appreciation

factor for flat cable current capacity. For all materials used for wiring conductors, increased temperature causes an increase in conductor resistance. At sufficiently higher temperatures, this increased resistance causes a requirement for reduction of current carrying capacity of round conductors as evidenced by note 1 to paragraph 6.5 of MIL-W-25038. The essence of the flat cable high ambient temperature appreciation factor is that the positive effect of increased radiation heat transfer more than offsets the negative effects of decreased free convection heat transfer and increased resistive heat generation. The net result is that for constant conditions of temperature rise and load current, the overall heat transfer rate from flat electrical cables (W/T = 150) becomes more effective as ambient temperature increases. It should be noted that an overall thermal radiation emissivity of 0.6 or greater is assumed for these calculations.

The graphical representations of the flat cable current capacity and voltage drop computer programs are given in the design guide (Section 4) of this report.

3.5.1.1 Flat Cable Transient Overload Considerations

Power supply surges will frequently occur during start-up of equipment, such as in an electric motor and other equipment which requires a dynamic inductive balance to impede excess current flow, and during switching of large loads. Voltage or current 'spikes' will also occur due to coupling of intense electromagnetic fields such as nuclear electromagnetic pulse (NEMP) and nearby lightning strikes. These power supply surges or spikes are usually referred to as transients.

For the conductors which must carry these transients, it is a requirement that the transients do not cause excessive heat damage of the harness. Damage to harnesses is almost always to the insulation material on the conductors.

Steady-state maximum insulation temperature ratings are not step functions, i.e., a few degrees of overheating will not instantaneously debilitate the insulation. Instead, there is a gradual increase in decomposition rate as the temperature increases. As an example, Kapton ® Type H-F insulation is rated for continuous operation at 200°C, but can be operated as high as 275°C for a period of several hours before significant damage results.

The heat generated by a transient is a function of the transient current squared, and the rate of heat dissipation is a function of the surface area. since flat cables (W/T = 150) have about 6.9 times greater surface area than same size round wires, then the square root of 6.9 yields the increase in transient capacity of 2.6 times for flat cables versus the same size round wire.

To allow for the simplifying assumptions in the above paragraph, the conservative design parameters used for flat cable transient capacity were 2.0 times the capacity of round wires for single conductors, and 1.5 times the capacity of round wires for stacked flat pairs. A chart for flat cable transient capacity is given as Figure 4.5.33 in the design guide (section 4.0).

For stacked flat cables, there might also be an inductive separation force

that would limit the allowable magnitude of a transient current. As this would depend on the cable construction details, the value of this limit could not be determined for this study's replacement harnesses.

### 3.5.2 Flat Cable Replacement Harness Shielding Requirements

The wide, flat form of flat cable "stretches out" the electromagnetic field lines concentric to the axis of the conductor. Hence, the intensity of the EM field around the conductor falls off more rapidly with distance from the conductor than with similar size round wires (see figure 3.5.2.1).

One result of this faster decreasing field is a reduced threat of coupling of flat cable harness EM emissions to adjacent circuits.

Using action-through-a-field coupling concepts (i.e., incident fields act on conductor fields, which propagate back to the cables), it can be stated that the coupling of a given incident EM field would be less to a flat conductor than to a similar size round wire.

In the case of a two-flat-conductor DC system where the separation between the conductors is quite small, there is a relatively large distributed capacitance compared to round wires which attenuates AC signals above a certain frequency.

In consideration of the above arguments, it can be said that flat conductors have a better performance than round wires where aircraft electromagnetic problems are considered (EMC, EMI, and EMP).

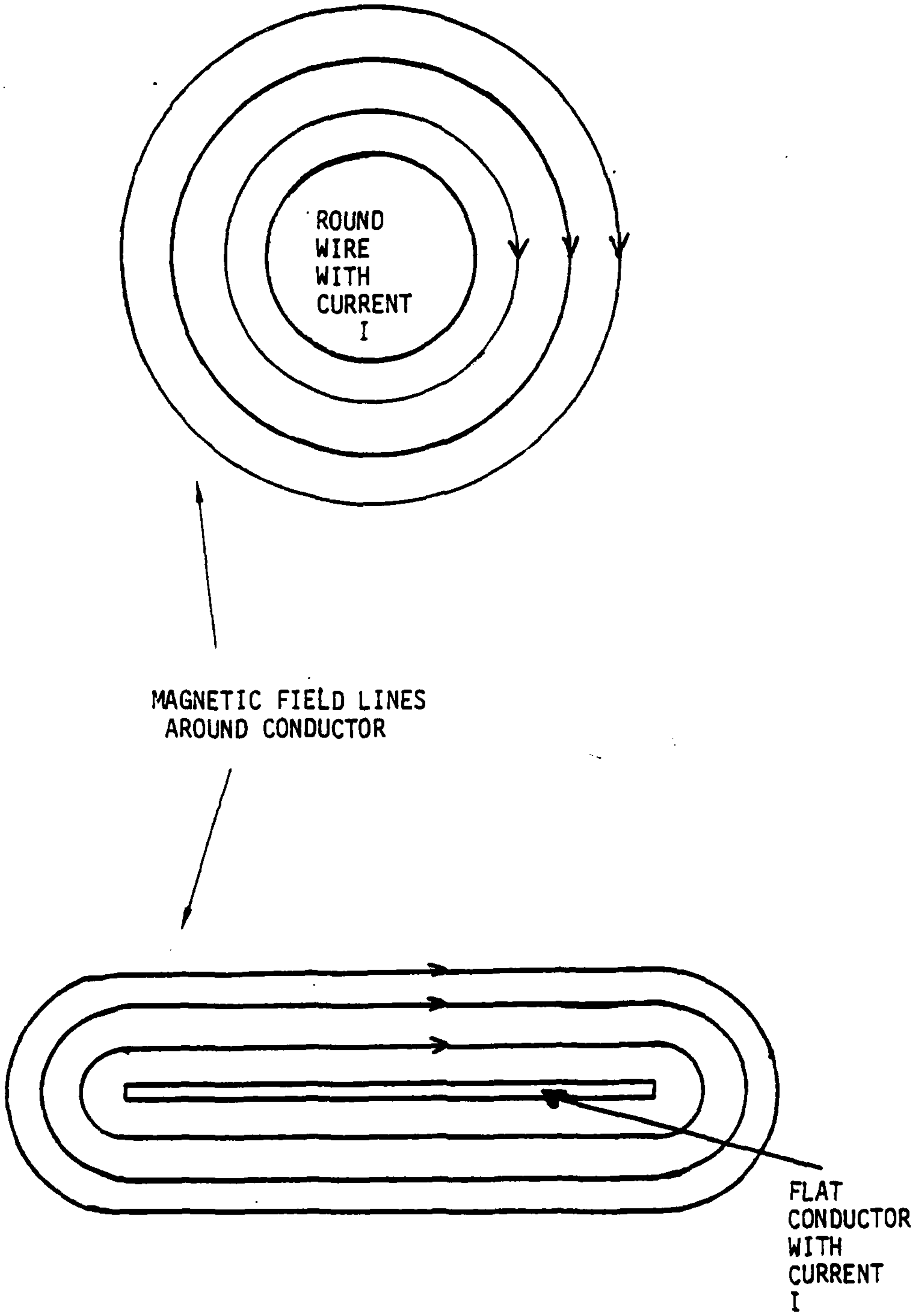



FIGURE 3.5.2.1

MAGNETIC FIELD LINES NEAR
FLAT VS ROUND CONDUCTORS

In an airframe which utilized flat power cable exclusively, the frequency of harnesses requiring shielding would be less than in the same airframe with round wire power harnesses. Lacking specific details of the airframe construction and the requirements of the replacement harness utilizing equipment, it is not possible to distinguish flat cable harnesses which do not require shielding from those that do. For our replacement harnesses, shielding was utilized on flat cables in exactly the same places as with the round wire harnesses. It should be noted that this practice does not adequately reflect the reduction in shielding weight that would occur with flat power cable usage.

An attempt was made to use braided wire shielding (Federal Specification QQ-B-575) on the flat power cable. It was later discovered that the increase in surface area caused an increase in the shield diameter and an associated severe weight penalty. The method finally settled on for shielding consisted of strips of reinforced foil wound in opposite directions around the conductor with small gauge drain wires at either conductor edge. As with the round wire shielding requirements (Section 3.4) this shielding method may not be the ultimate choice, and the associated weight and cost of shielding for the flat cable harnesses in this study are again representative.

Abrasion sleeving was used for flat cable in the same locations it was used for round wire. Unlike the shielding, there was only a slight weight penalty associated with using round wire sleeving on the flat cable, and was therefore considered accaptable.

### 3.5.3 Flat Cable Replacement Harness Configuration Optimizing

#### 3.5.3.1 Width to Thickness Ratio Selection

This study was to consider width to thickness (W/T) ratios in the range from 150 to 200. We do not recommend going above a W/T of 150. The reasoning for this is quite straightforward.

From the computer calculations mentioned in Section 3.5.1, it was observed that when all other factors were equal, a change in W/T from 150 to 200 resulted in an increase in current capacity of from 5 to 10%. This small a change would probably not cause a downshift from one flat cable standard size to the next, so no weight savings would occur in most cases.

Assuming that weight savings would be the only potential benefit from the increased W/T, and since this benefit does not develop in most cases, the penalties far outweigh the benefits:

a. The larger W/T results in a 16% increase in width, a severe space and routing penalty.

b. There is an 18% decrease in thickness, which is a further hazard to mechanical strength and which adds difficulty to the wire manufacturing process.

Perhaps, in the future, when the standard sizes and manufacturing methods for flat cable have been more completely investigated, it can be shown to be

feasible to use larger values of width to thickness than the 150 used for this study's replacement designs.

3.5.3.2 Two Wire Systems Layout Selection - Stacked or Side-By-Side

Configuration of the two wire flat cable runs can take one of two forms: conductors placed "side by side", or "stacked" one above the other. In the"side by side" configuration, the advantages are as follows: Thermal dissipation is not impeded as it would be in a "stacked" configuration, also termination to a terminal block over that of the "stacked" configuration is simpler. The disadvantage: greater susceptibility to damage, occupying more room in the aircraft, larger clamps for attachment, resulting in a heavier and more costly installation, negligible capacitance, hence no filtering effect during nearby lightning strike or nuclear EMP conditions.

In the "stacked" configuration: Advantages — The filtering capability is increased due to the increased capacitance between conductors. Also, this configuration requires less space. Disadvantages — Termination requires more complex terminal blocks or special connectors, and thermal dissipation is not as efficient.

When the filtering capability is lost by placing the conductors side-by-side, the incidence of harnesses requiring shielding increases. Due to the increase in shielding weight that would occur, the side-by-side configuration was not used in this study's replacement designs.

### 3.5.4 Flat Cable Insulation Selection

One insulation system chosen for the replacement harnesses is a combination of FEP and polyimide. This combination is in current use on a large percentage of military flight-equipment wiring. It is an excellent system in terms of all phases of performance. It is very tough, resists heat, light, chemicals and other environmental hazards, has a relatively low density and high electrical resistance properties. In addition to these factors, the current method of manufacturing for round wire would probably be easily adapted to flat cable manufacture.

This round wire method consists of the following:

a. A thin (0.1 to 0.5 mil) film of FEP is bonded to a thin (1.0 mil) film of polyimide, on one or both sides. This film is then cut into long strips, approximately 1.0 inches wide.

b. These strips are then wrapped onto the wire in several layers, each layer wrapped in a different direction.

c. The layers are then formed together under high heat and pressure to give consistent insulation along the length of the wire. This method would be easily adapted to flat cable by simply laminating the conductor with the layers of tape. It would probably not be necessary to wrap the tape, instead it would be sufficient to layer the strips parallel to the conductor with an overlap at the conductor edge.

These details would best be worked out with a cable manufacturer. For the

purposes of this study's design, we will use a total insulation thickness of 6.0 mils, which would contain equal quantities of FEP and polyimide. This insulation would be sufficient for the usual 600 volt rating given in most military specifications for round wire. This insulation would have a specific gravity of 1.78 and a temperature rating of 200 °C.

There are some drawbacks to this type of insulation. The material is expensive compared to other insulators in its class. Also, it is tough enough to possibly give some problems in stripping.

The FEP-PI insulation was used on all replacement harnesses except W0294 in the engine compartment. FEP-PI's temperature rating of 200 °C would be insufficient in the engine compartment area (ambient temperature = 215 °C). For W0294, Tetra Fluoroethylene (TFE) was used, with a temperature rating of 260 °C. It is anticipated that this insulation would be difficult (therefore expensive) to apply to flat cable.

Cost estimates from various manufacturers were in the range of 30% greater for flat cable than the same size round wire with a similar insulation.

3.5.5 Terminations and Splicing of the Flat Cable Replacement Harnesses

For this study's harness designs, only existing off-the-shelf hardware or existing technologies were used. The reasoning was that the deficiencies in the state-of-the-art would be exposed in the comparative analysis and this would aid prioritizing areas of flat cable usage requiring development.

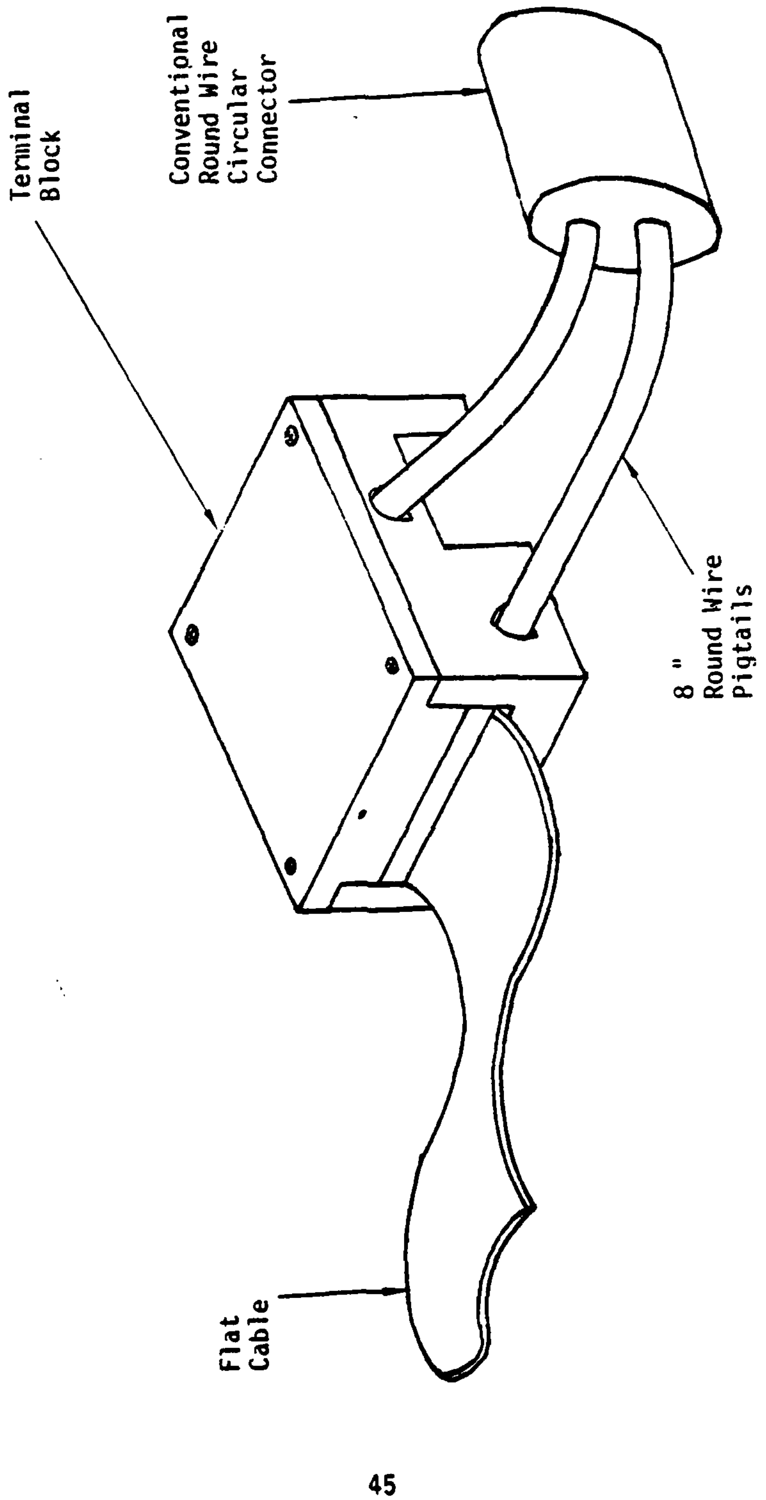



FIGURE 3.5.5.1
TYPICAL TRANSITION FROM
FLAT TO ROUND CABLE
VIA TERMINAL BLOCK

One area where aerospace usage of flat cable is deficient is terminals. For the harness designs, a transition terminal block was used for interfacing with round wire connectors where required. See Figure 3.5.5.1 for a typical example. The terminal blocks were not used for the firewall connector due to a high weight penalty, so the guideline of staying close to the state-of-the-art had to be departed from for the firewall connector. The design of the firewall connector would be similar to the connector shown in Figure 4.8.1 of the design guide. Splices were considered to be currently available by using Amp, Inc. Termi-Foil splices. A typical Termi-Foil unit can be seen in Appendix C.

### 3.5.6 Methods of Providing Slack in Flat Cable Harnesses

Slack is required in any aircraft harness for the following reasons:

1. Allowance for cable retermination (usually 3 reterminations during a harness' lifetime are required).

2. Allowance for length change due to airframe flexing.

3. Allowance for thermal expansion/contraction of the airframe and the wire harness.

The following methods of providing slack have been considered and evaluated (See Figure 3.5.6.1):

a. A flattened "U" bend.

b. An accordion configuration.

c. An "S" bend, which is an enlarged accordian with only 2 direction changes.

d. A spring loaded plastic roller, around which the flat cable could be wrapped and dispensed from.

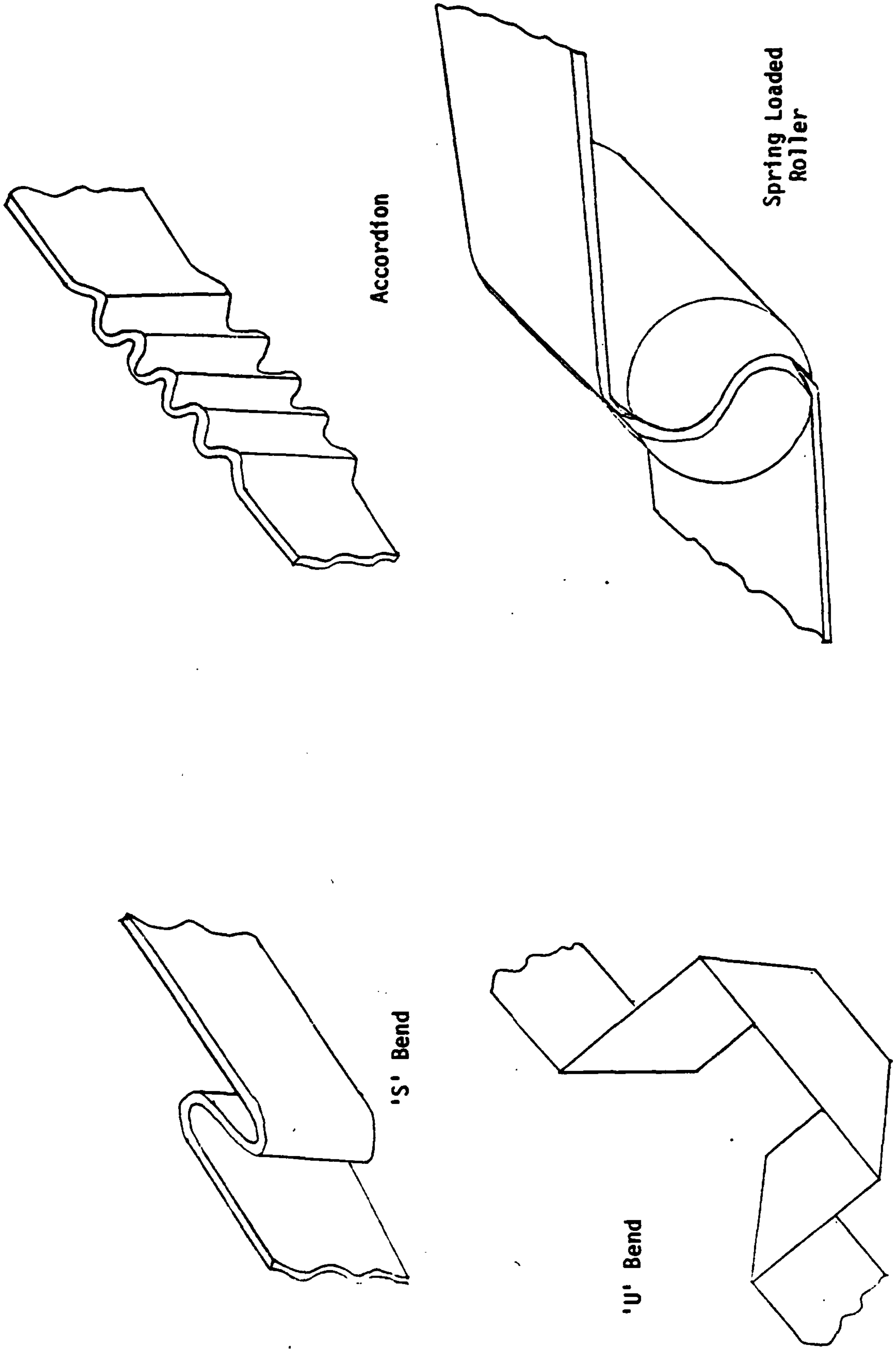



FIGURE 3.5.6.1
CONCEPTS OF PROVIDING SLACK

The advantages and disadvantages of the above four areas are shown below:

a. Merits: Lowest profile

Risks: Larger surface required, possibility of work hardening at the folds.

b. Merits: Lowest total space penalty

Risks: Excess could "flop around" and become damaged.

c. Merits: Easiest to construct

Risks: Excess could "flop around" and become damaged.

d. Merits: Cable remains moderately taut.

Risks: Cost and weight penalty of extra device.

Out of these possibilities, #3, the accordion configuration, is considered the best overall performer, followed by numbers 4, 2 and 1, in order of decreasing performance.

The accordion configuration will be utilized in this study's design, and the spring loaded roller should be considered at a later date for future development.

### 3.5.7 Flat Cable Identification Methods

#### 3.5.7.1 Significant Identification

The following parameters are of significance when identifying flat cable:

a. Conductor material (copper or aluminum)

b. Conductor plating (if any)

c. Conductor size

d. Width to thickness ratio

e. Insulation material

f. Temperature rating

g. Voltage rating

h. The circuit number assigned to a harness on an engineering drawing

#### 3.5.7.2 Methods of Identification Coding

Current military practice for information coding of items (a) through (g) above (for round wire) usually consists of referring to a specification which details all items except item (c), conductor size. It is anticipated that item (d), width-to-thickness ratio, will become constant at 150; this would also be fixed by the specification number.

The designation of the size of the conductor could be based on an equivalent system of round wire AWG numbers.

3.5.7.3 Physical Attachment of Codes

A wide range of physical identification methods are avaiable, such as color coding, stripes, adhesive labels, imprinting, and hot stamping.

This study's flat cable replacement harnesses shall utilize the last two methods, as the tools and procedures are most used, the methods are easily adapted to flat cable, and the tools would require little modification.

Items (a), (b) and (d) to (g) from 3.5.7.1 would be represented by a MIL SPEC number and would be imprinted at the time of cable manufacture. Item (c) would be represented by an AWG equivalent gauge number and imprinted at the time of cable manufacture. Item (h) would be represented by a series of letters and/or numbers taken from engineering drawings. These would be hot stamped prior to installation. All markings would be repeated at 15 inch intervals, except near the ends. The markings for item (h) would be repeated at 3.0 inch intervals for 2.0 feet at the harness ends.

### 3.5.8 Methods of Clamping and Supporting Flat Cable

A conceptual design for a high temperature clamp is shown in Figure 3.5.8.1. A low temperature clamp would be similar in design, the differences being that the metal frame could be replaced with nylon and the silicone cushion could be a neoprene material.

As shown, attachment of clamps could be with screws to a metal structure or adhesives to a composite structure.

### 3.5.9 Flat Cable Replacement Harness Design Summary

The harnesses are shown schematically in Figures 3.5.9.1 through 3.5.9.8. Installation illustrations are shown in Figures 3.5.9.9 through 3.5.9.12. The installation route for the flat cable is essentially the same as for the round wire replacement harnesses. The length of the flat cable harnesses is increased slightly due to the longer path of travel for the right angle bends. (Approximately 2 inches per bend).

### 3.5.10 Flat Cable Installation Methods

General installation methods are covered in Section 4.9 of the Design Guide.

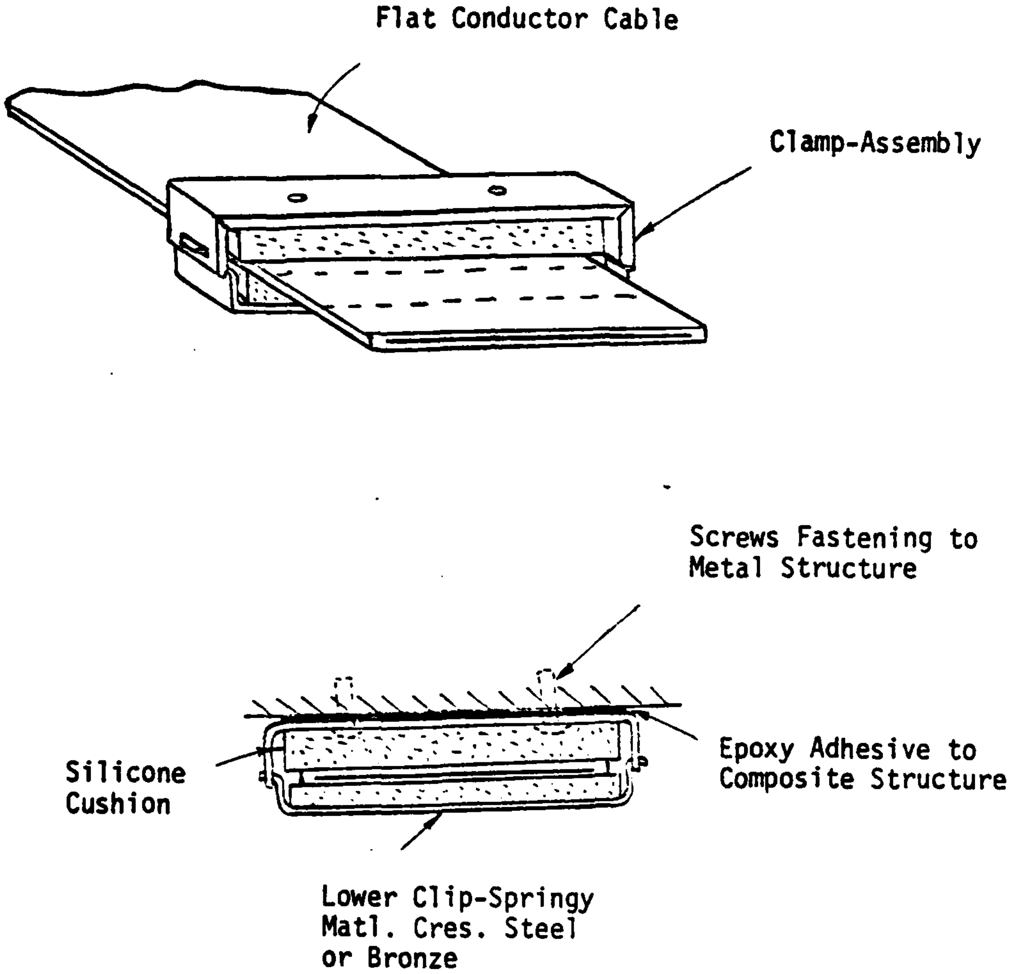



FIGURE 3.5.8.1

HIGH TEMPERATURE - CLAMP ASSEMBLY
FLAT CONDUCTOR CABLE

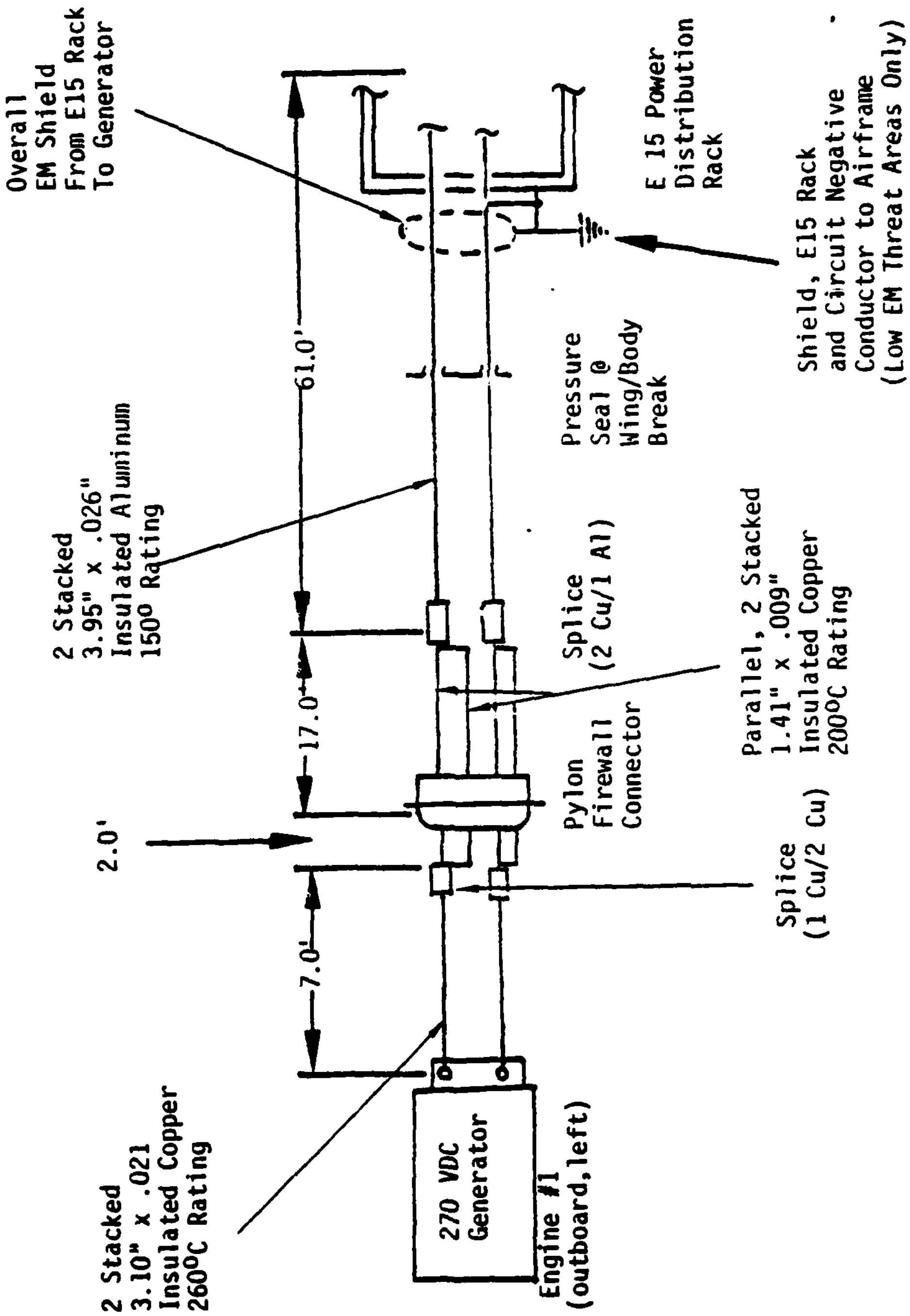



FIGURE 3.5.9.1

HIGH AMPACITY (W0294 and W0322) FLAT CABLE REPLACEMENT
HARNESSES IN COMPOSITE AIRFRAMES
(SCHEMATIC DIAGRAM)

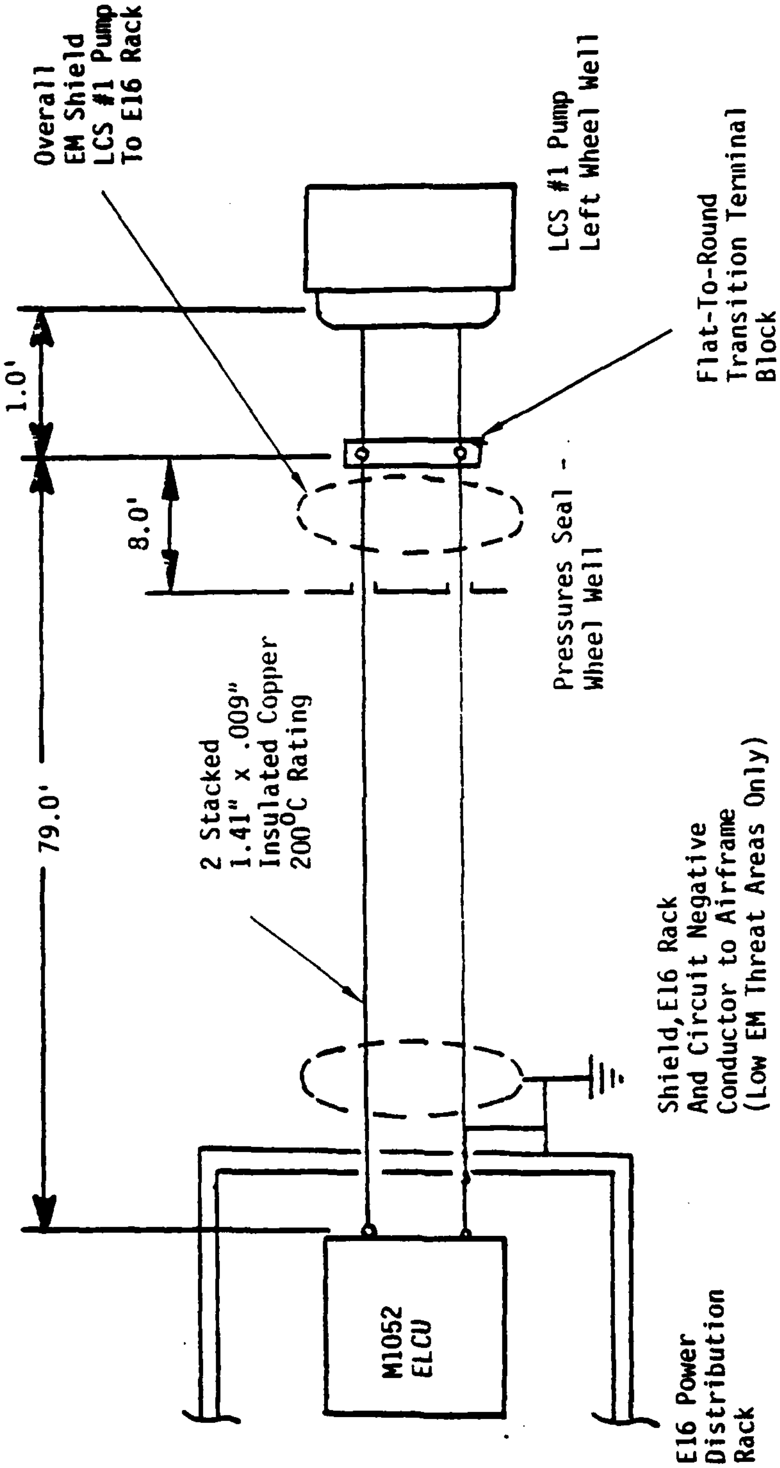



FIGURE 3.5.9.2

MEDIUM AMPACITY (W0844) FLAT CABLE
REPLACEMENT HARNESS IN COMPOSITE AIRFRAMES
(SCHEMATIC DIAGRAM)

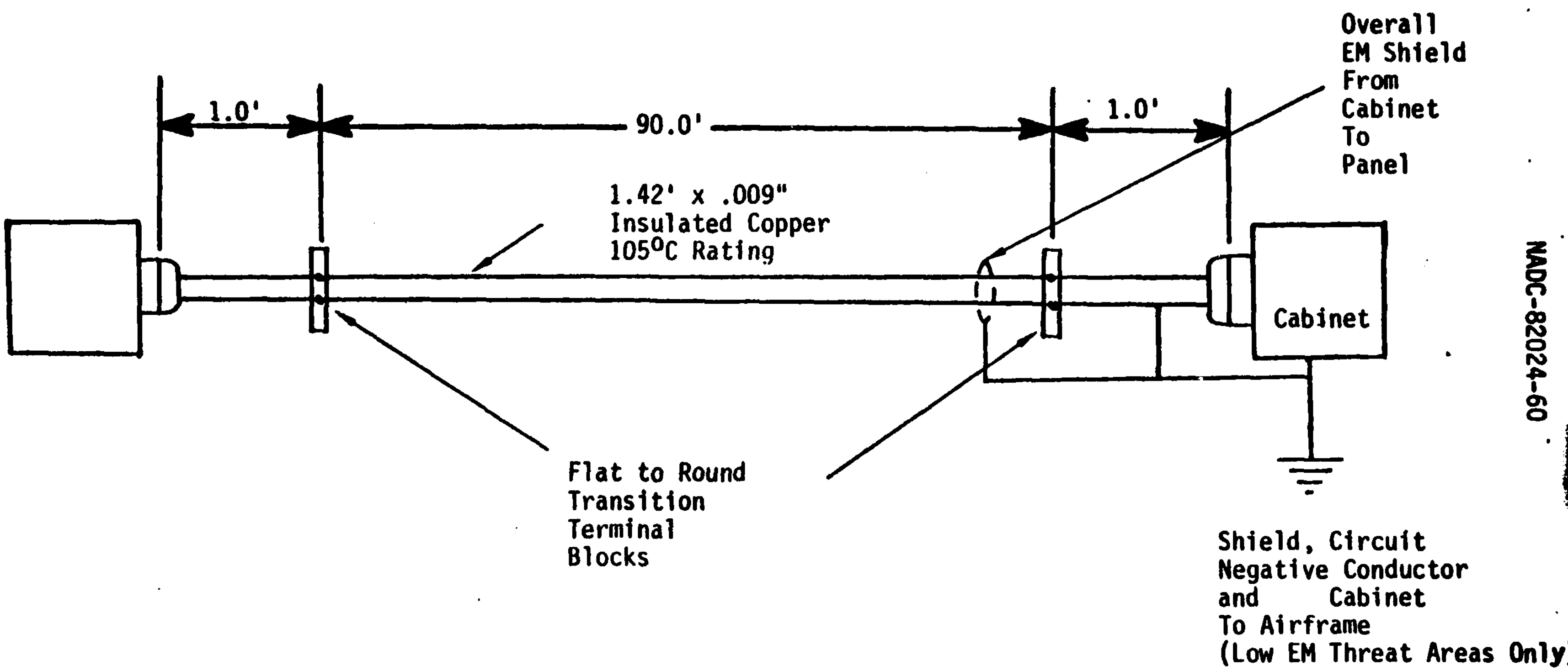



FIGURE 3.5.9.3

LOW-1 AMPACITY (W2343) FLAT CABLE REPLACEMENT HARNESS IN COMPOSITE AIRFRAMES (SCHEMATIC DIAGRAM)

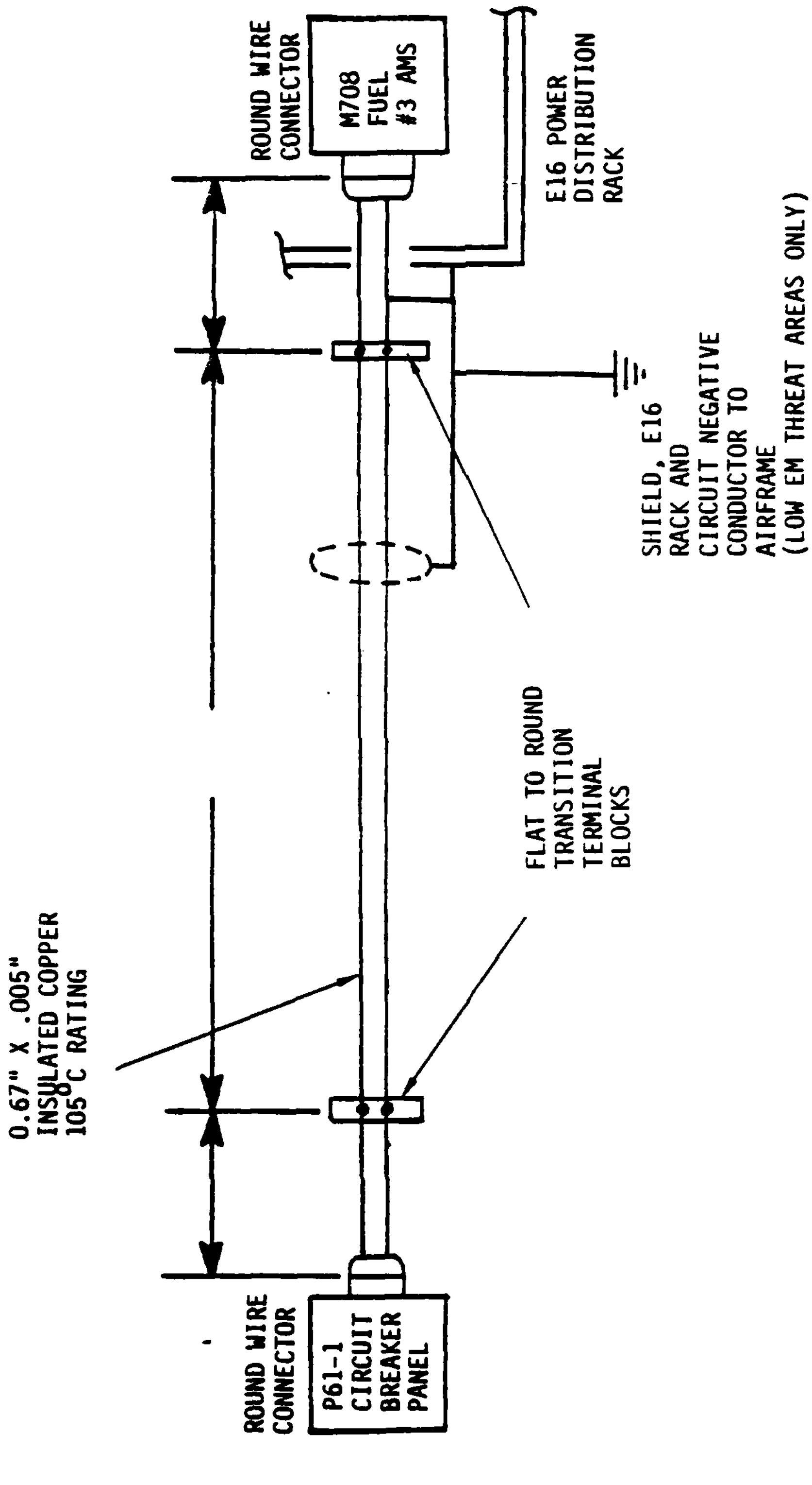



FIGURE 3.5.9.4
LOW-2 AMPACITY (W0708)
FLAT CONDUCTOR REPLACEMENT HARNESS
IN COMPOSITE AIRFRAMES
(SCHEMATIC DIAGRAM)

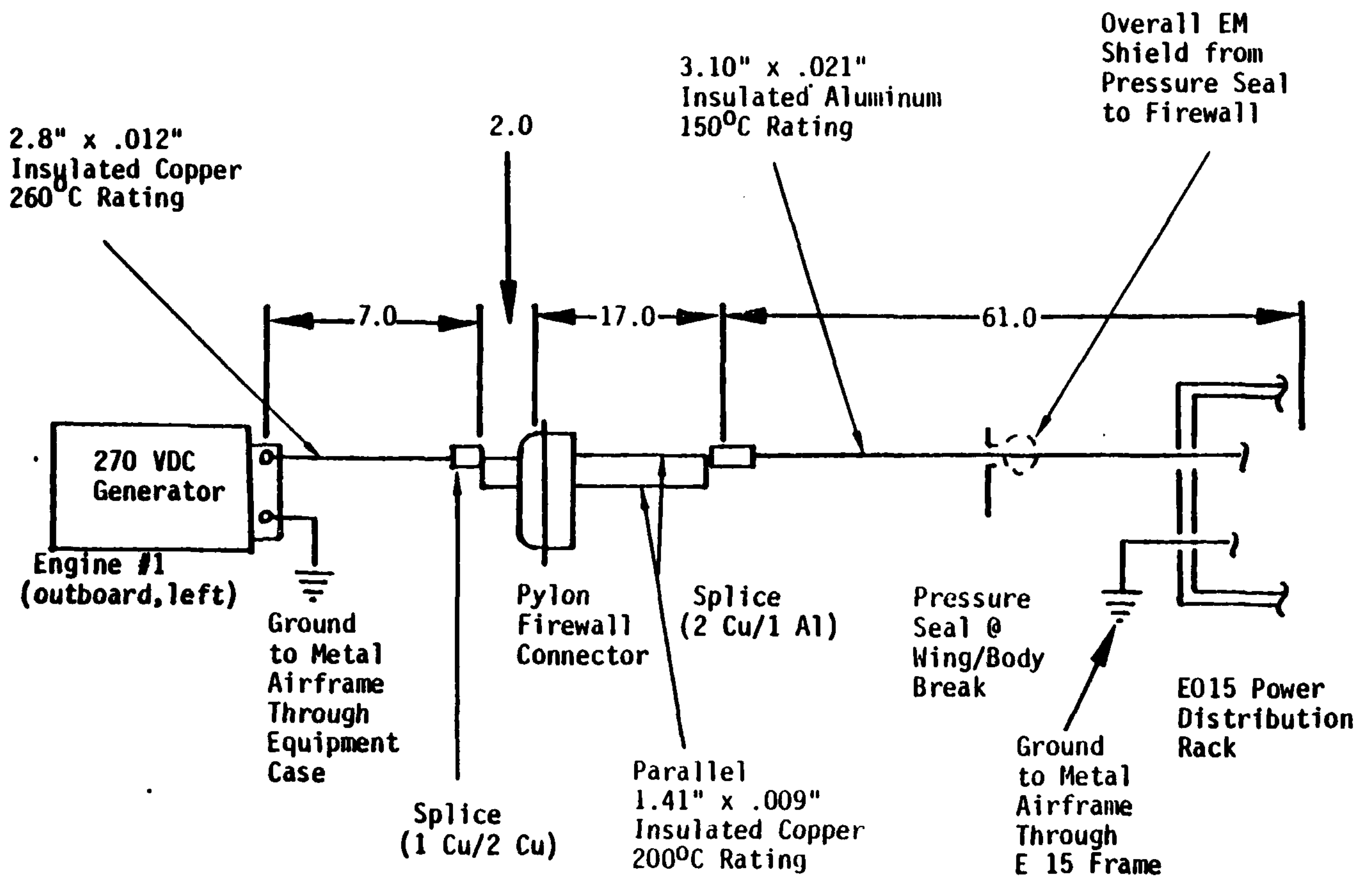



FIGURE 3.5.9.5

HIGH AMPACITY (W0294 & W0322) FLAT CABLE
REPLACEMENT HARNESS IN METAL AIRFRAMES
(SCHEMATIC DIAGRAM)

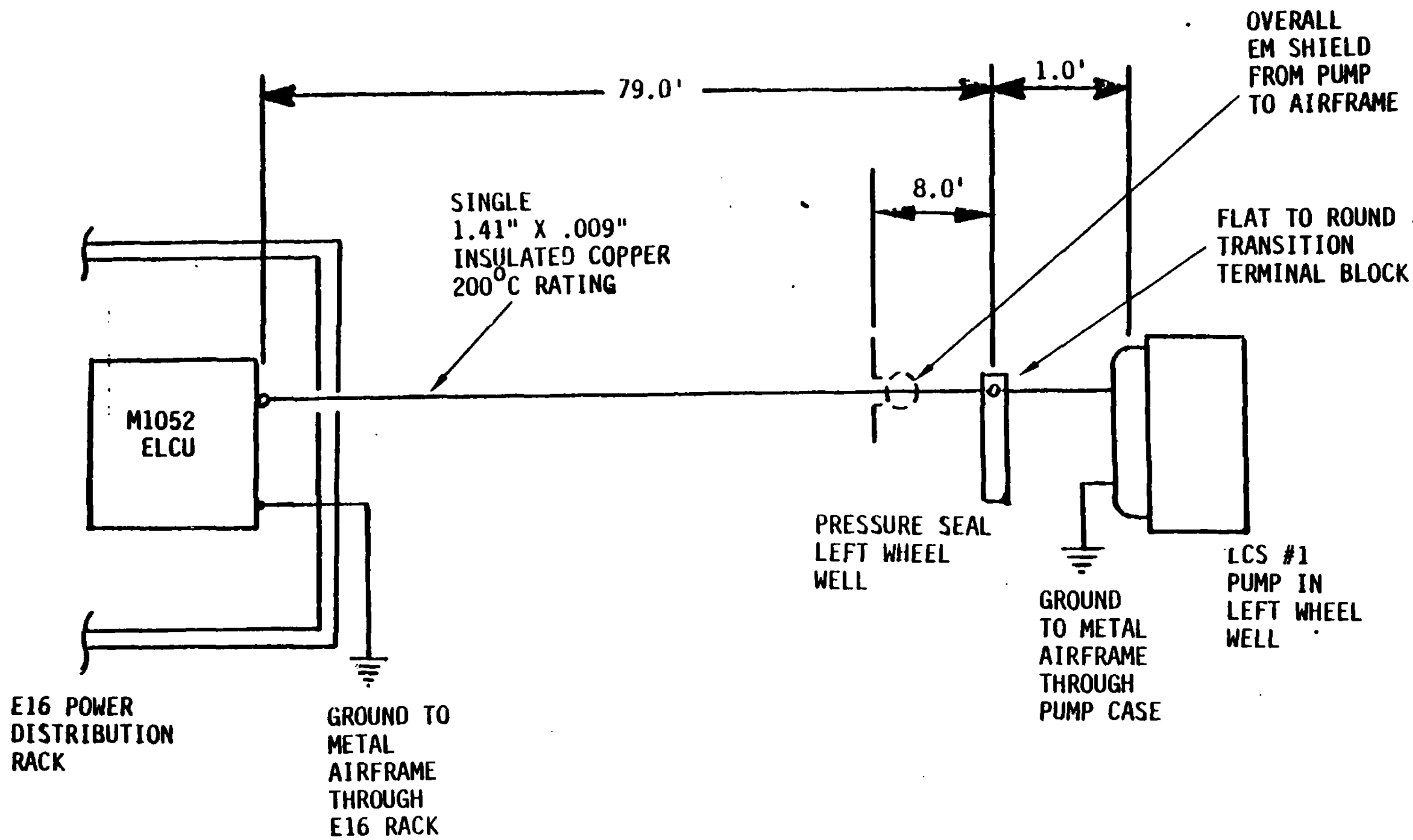



FIGURE 3.5.9.6.
MEDIUM AMPACITY (W0844) FLAT CONDUCTOR REPLACEMENT HARNESS IN METAL AIRFRAMES
(SCHEMATIC DIAGRAM)

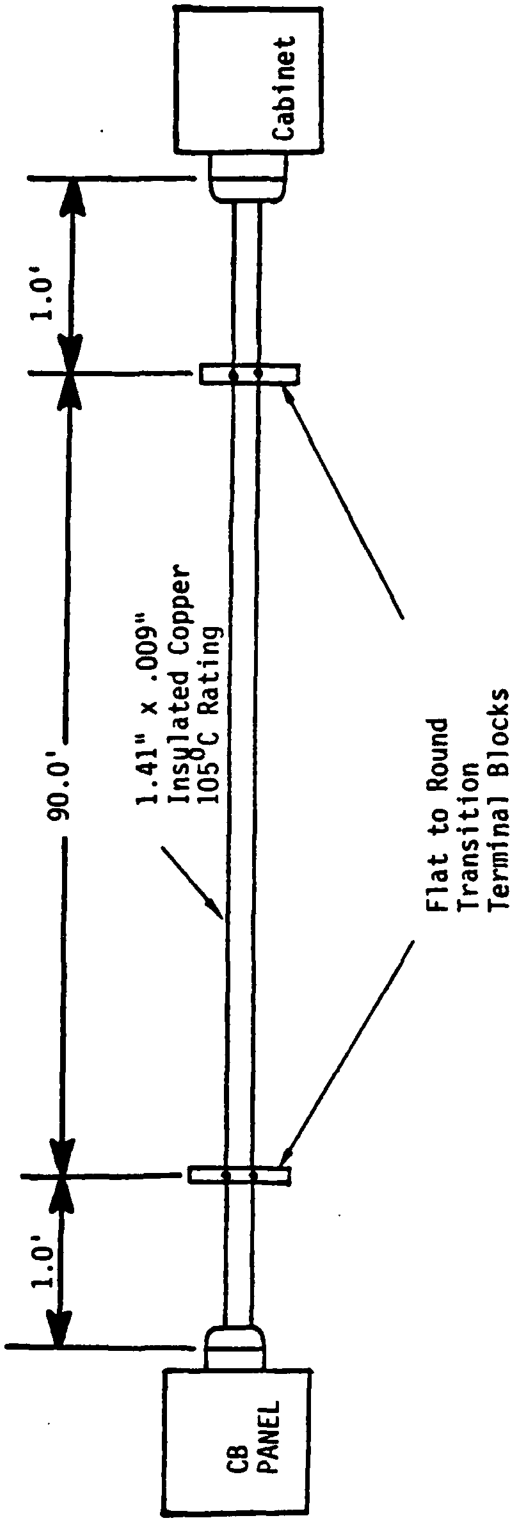



FIGURE 3.5.9.7

LOW-1 AMPACITY (W2343) FLAT CABLE REPLACEMENT
HARNESS IN COMPOSITE AIRFRAMES
(SCHEMATIC DIAGRAM)

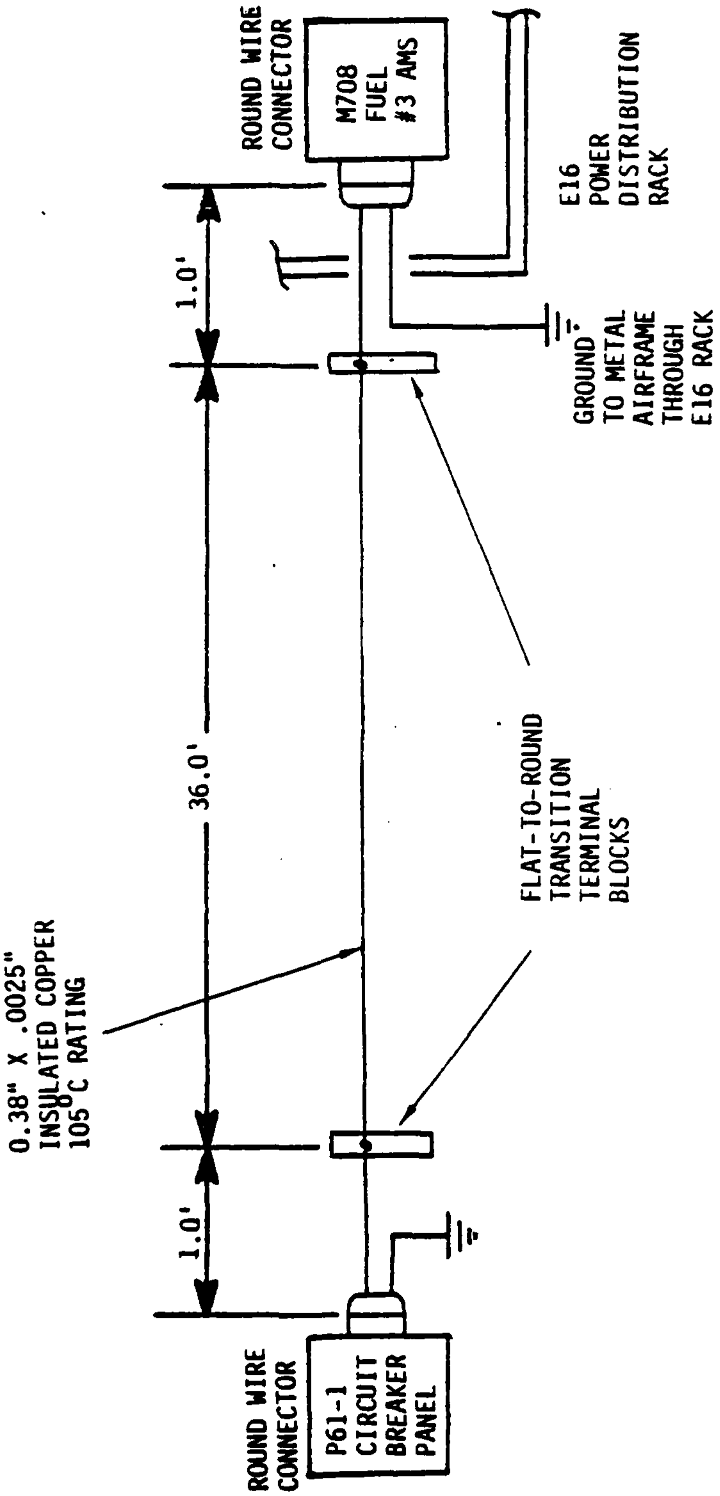
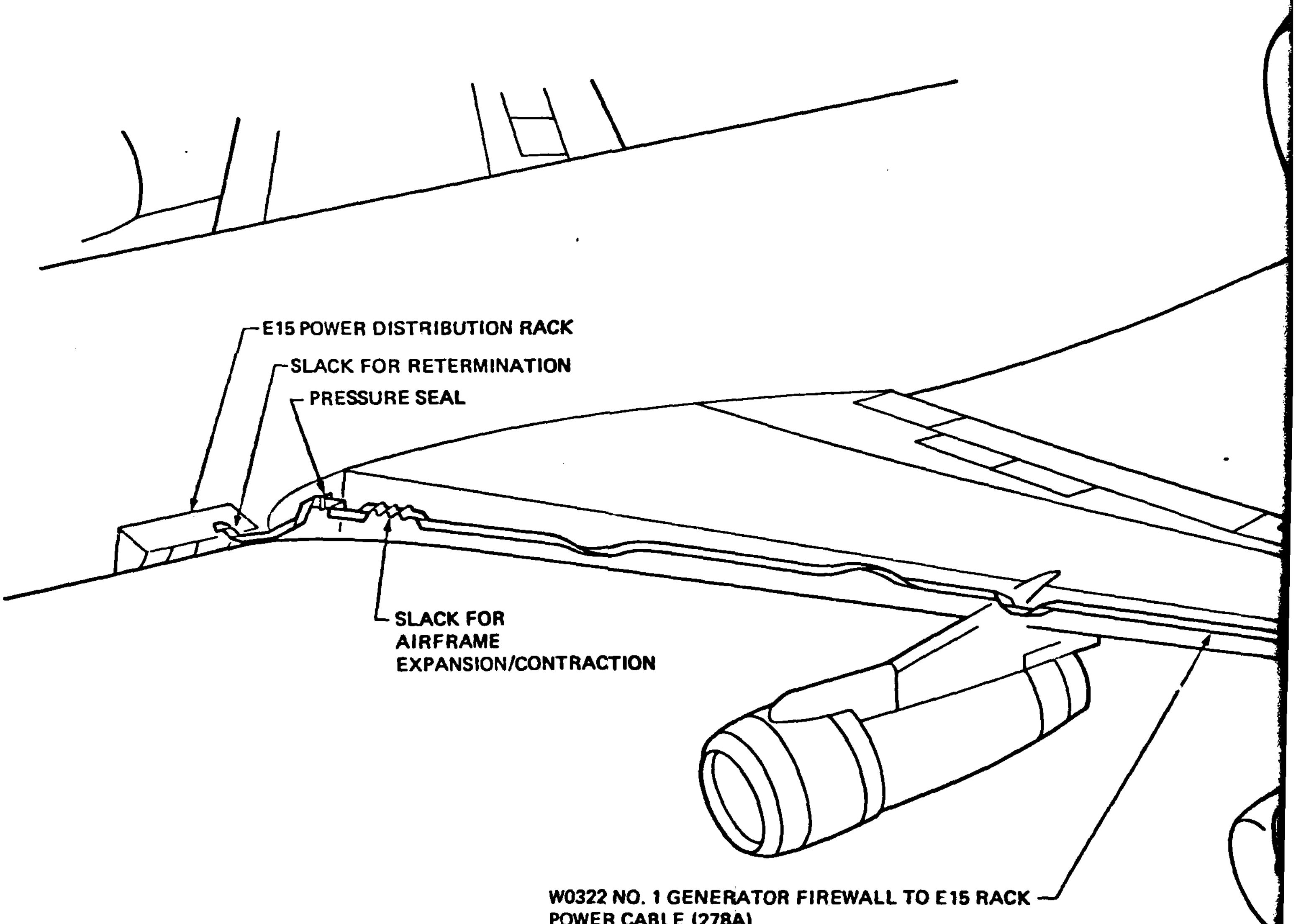



FIGURE 3.5.9.8
LOW-2 AMPACITY (W0708)
FLAT CONDUCTOR REPLACEMENT HARNESS
IN METAL AIRFRAMES
(SCHEMATIC DIAGRAM)


E15 POWER DISTRIBUTION RACK
SLACK FOR RETERMINATION
PRESSURE SEAL
SLACK FOR
AIRFRAME
EXPANSION/CONTRACTION
W0322 NO. 1 GENERATOR FIREWALL TO E15 RACK
POWER CABLE (278A)

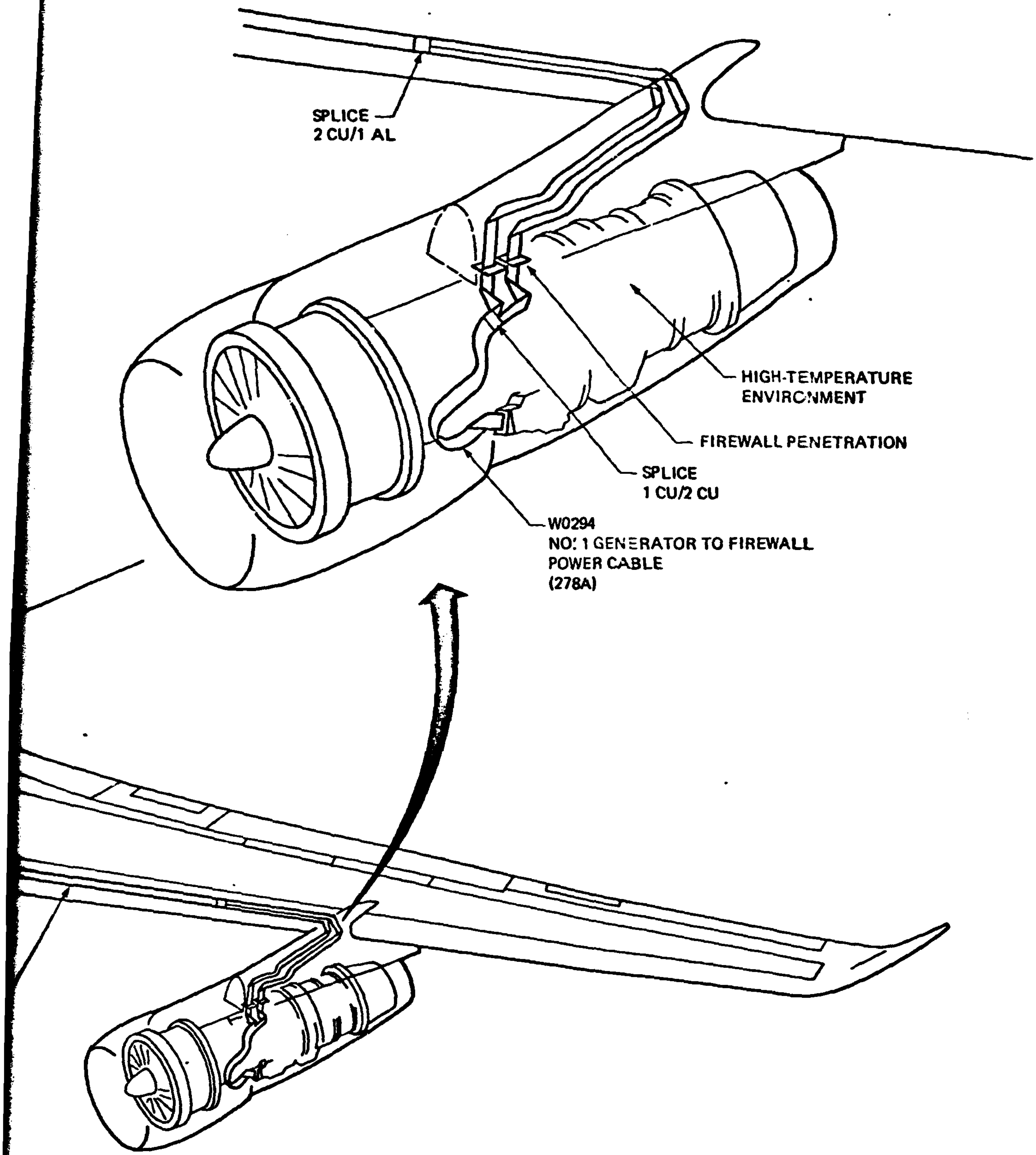
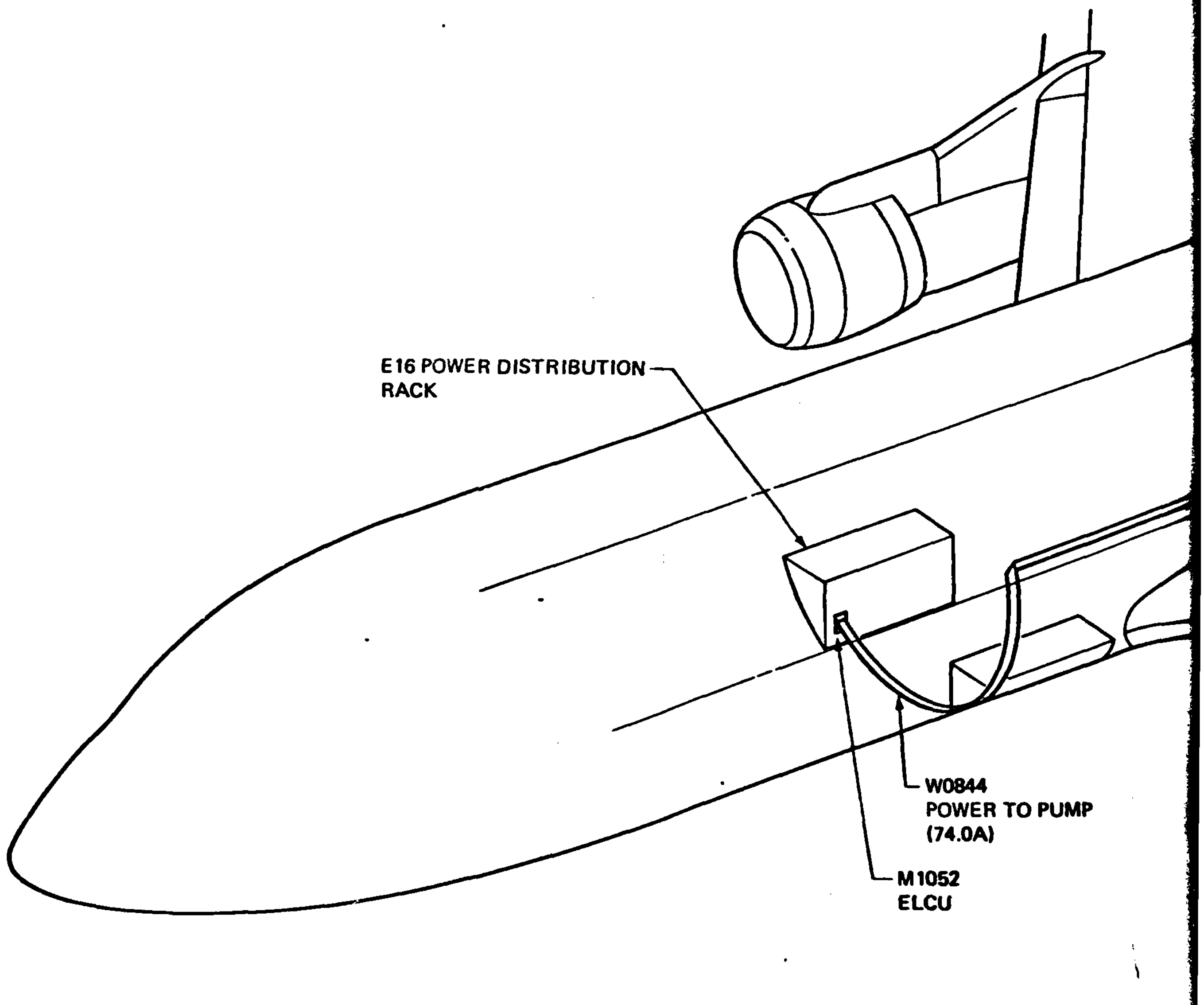



Figure 3.5.9.9 *High Ampacity Flat Cable Replacement Harness Installation*

12


E16 POWER DISTRIBUTION
RACK
W0844
POWER TO PUMP
(74.0A)
M1052
ELCU

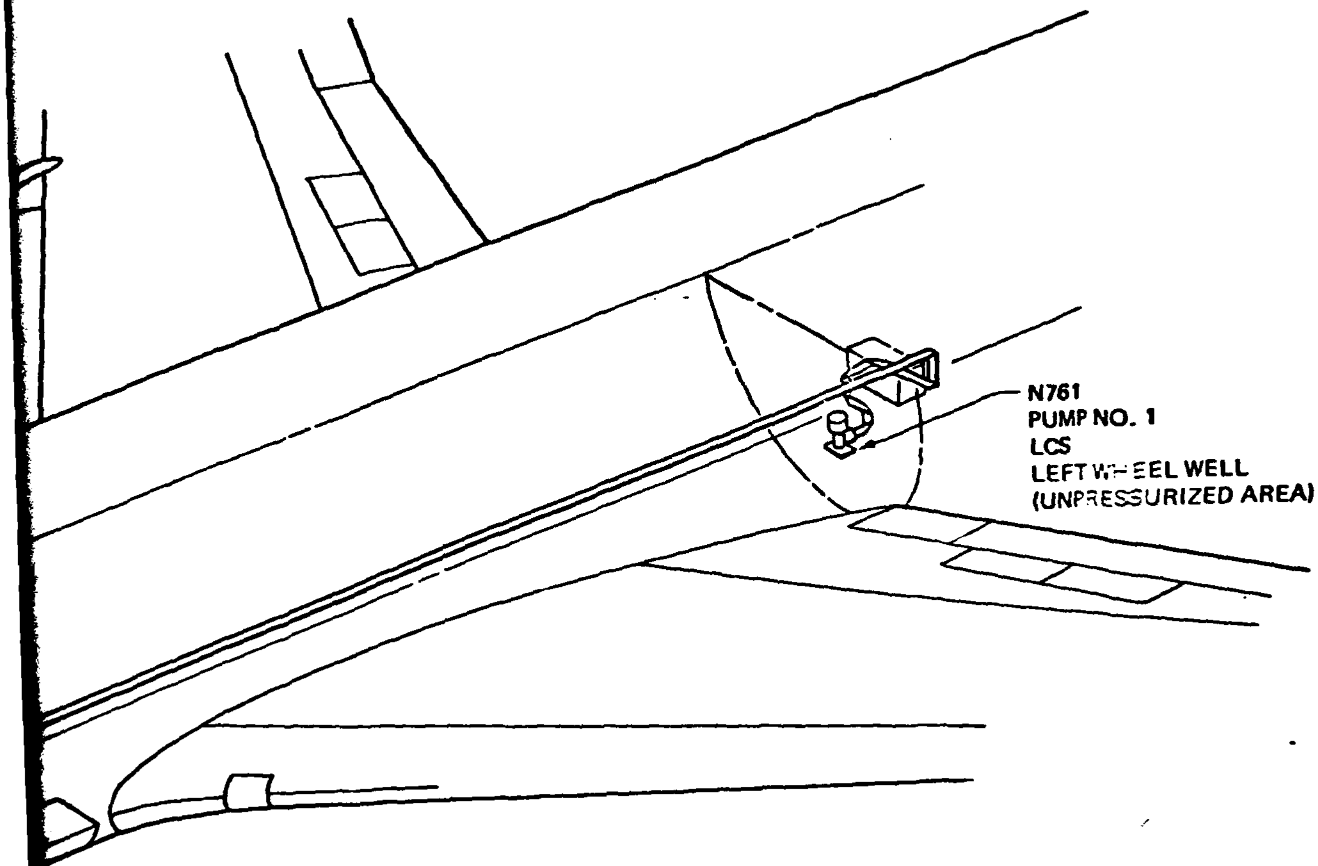
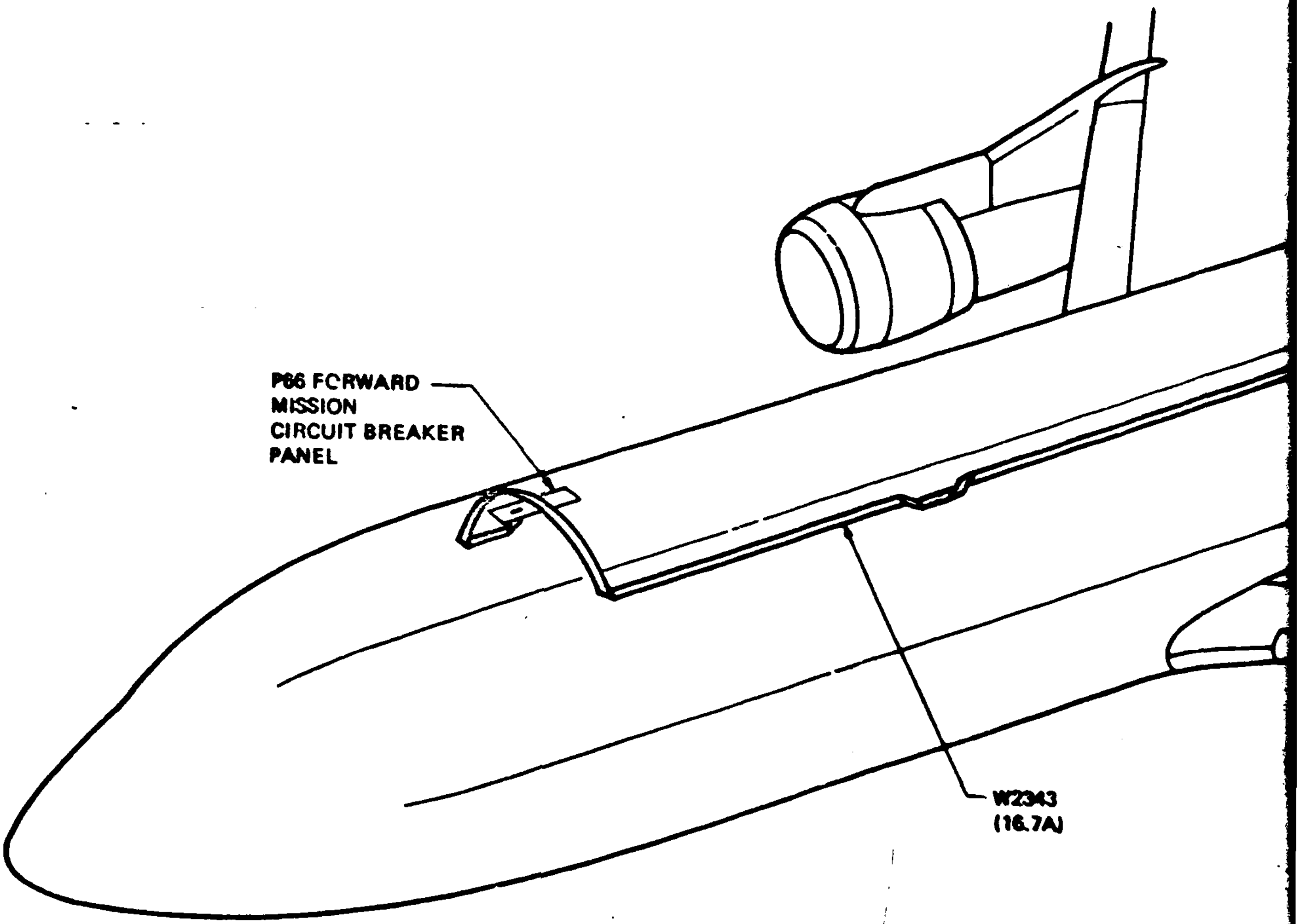



Figure 3.5.9.10 *Medium Ampacity Flat Cable Replacement Harness Installation*


P66 FORWARD
MISSION
CIRCUIT BREAKER
PANEL
W2343
(16.7A)

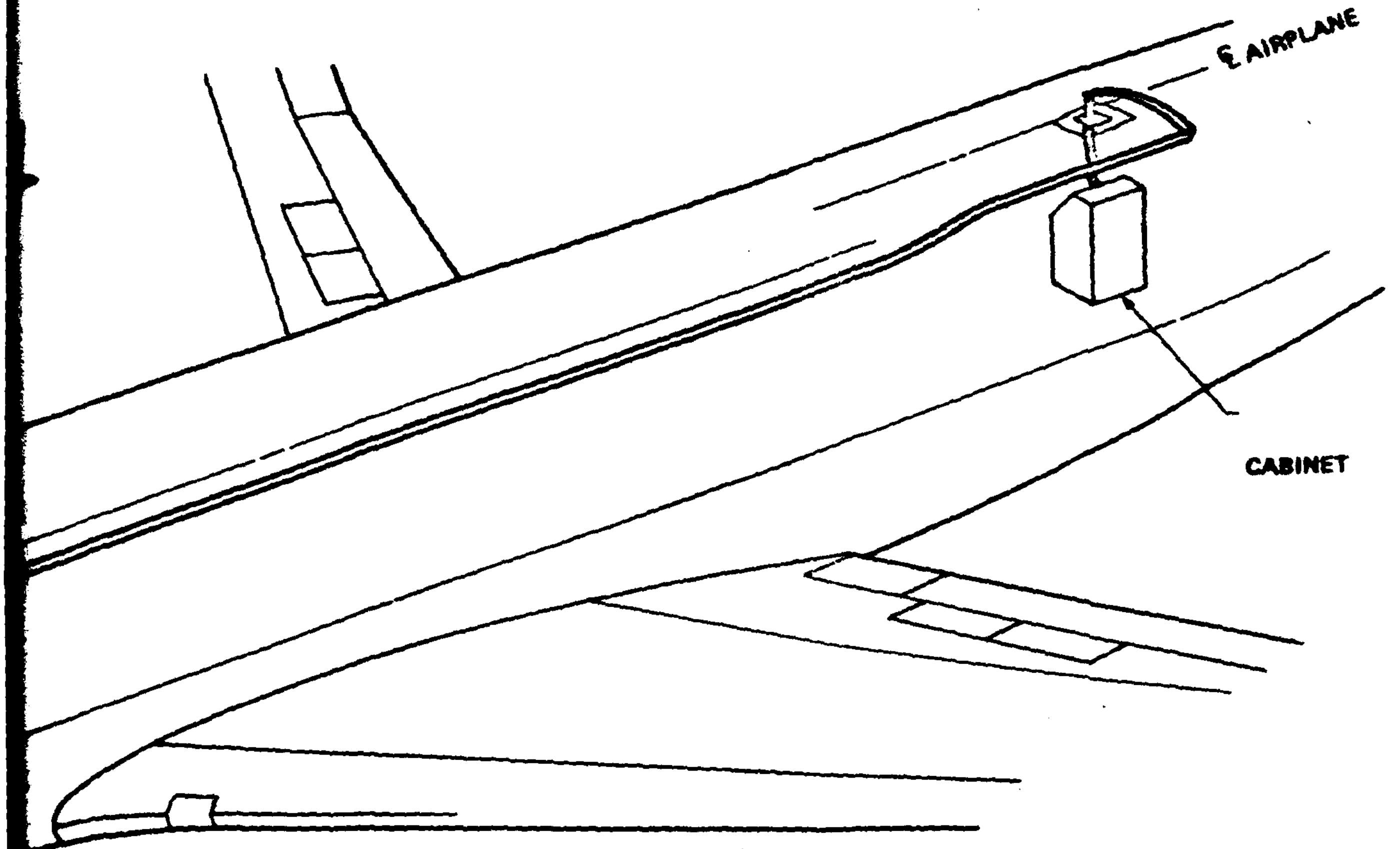
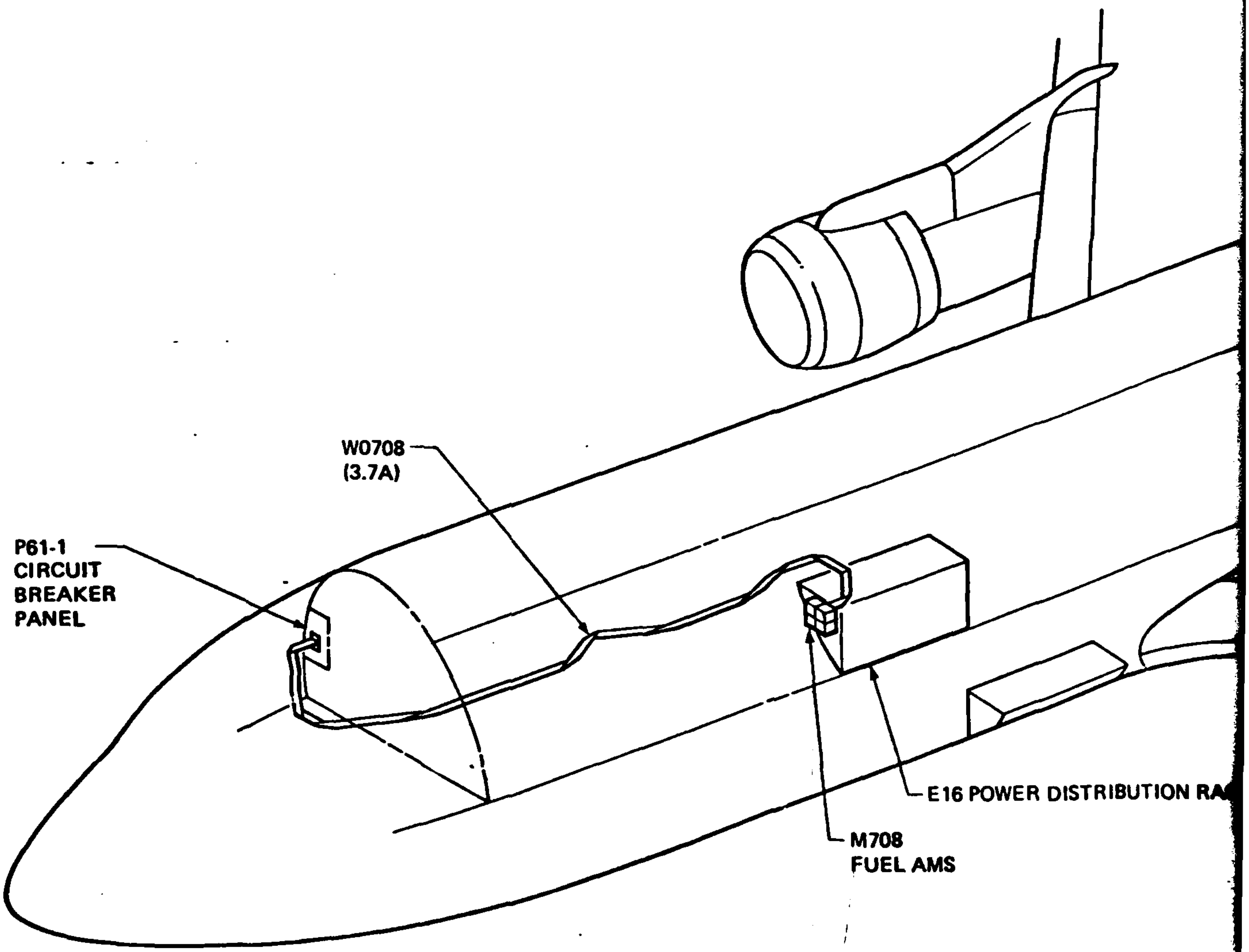



Figure 3.5.9.11 *Low-1 Ampacity Flat Cable Replacement Harness Installation*

1 2


W0708
(3.7A)
P61-1
CIRCUIT
BREAKER
PANEL
E16 POWER DISTRIBUTION RA
M708
FUEL AMS

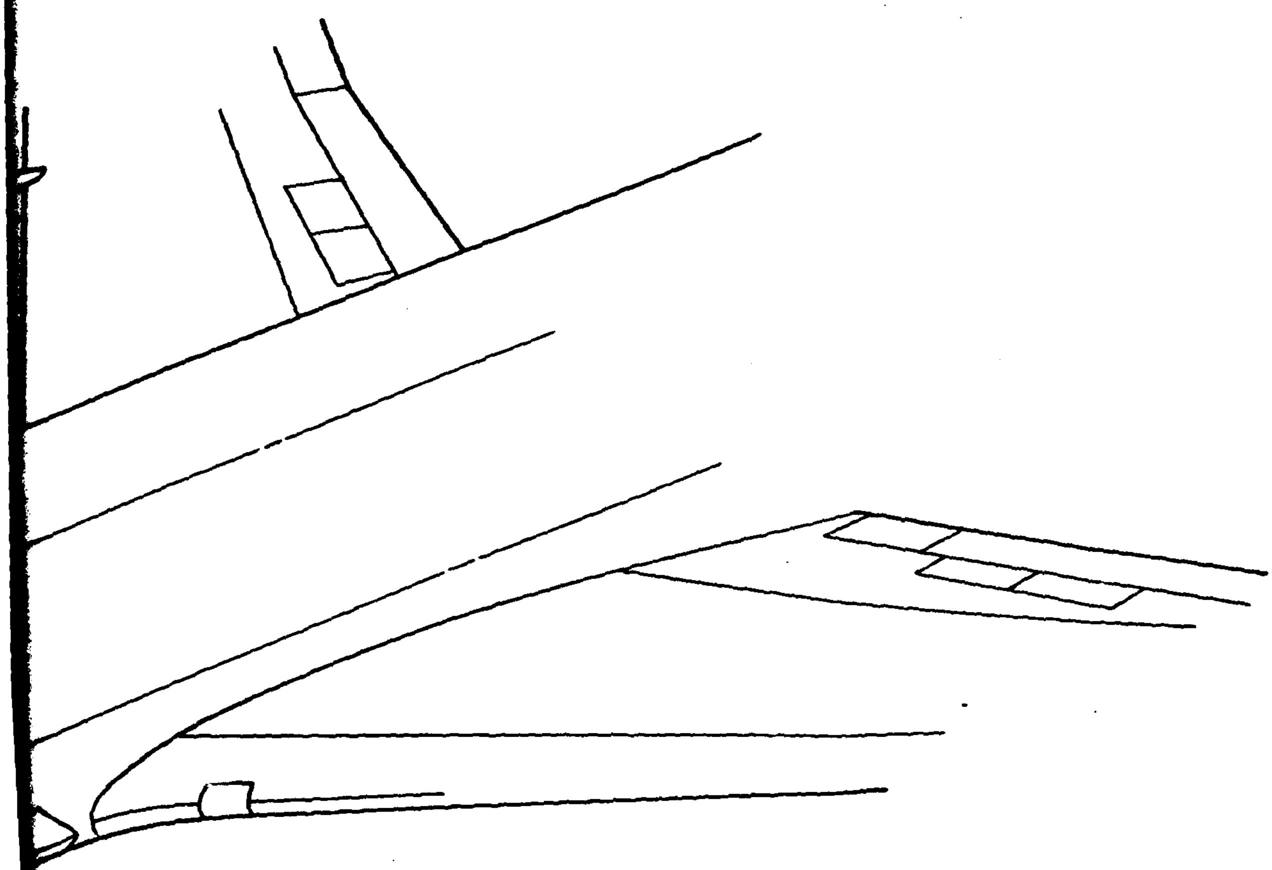



Figure 3.5.9.12 *Low-2 Ampacity Flat Cable Replacement Harness Installation*

2

## 3.6 Replacement Harnesses Round Versus Flat Conductor Comparative Analysis

### 3.6.1 Harness Weight Comparisons

Tabulation of the weights of each component for each harness in the different airframes can be seen in Appendix C. Following the tabulation sheets, estimates of non-existent flat cable components are given.

The results show a favorable weight effect for the use of flat cable versus round cable for runs greater than approximately 15 amps. Figures 3.6.1.1 & 2 show a summary of the effects in tabular and graphical form, respectively. Table 3.6.1.3 shows the weight of the existing AC system harnesses.

The exact current rating where the decrease in cable weight exceeds the increase in component weight should not be taken directly from Figure 3.6.1.2 due to the different characteristics of the 16.7 amp run. One of the differences of this run is that it is unusually long; this requires the conductor to be larger to avoid an excessive voltage drop. The other major difference is that it is a two wire run in both metal and composite aircraft. This is also for voltage drop considerations due to the large number of riveted areas in the structural return path of this run. Due to these differences, the crossover current rating for the average runs found in most aircraft would be closer to 10 amps.

In a generalized summary, if the total E-3A power distribution system was

converted to flat cable a significant weight savings would result. The E-3A aircraft which contains the baseline wire harness assemblies contains approximately 1,000 wire harnesses or cables with a total weight of 5,685 pounds. The power distribution system weighs 2,929 lbs of the 5,685 lb total weight. If from the Figure 3.6.1.2 graph a 30% average weight savings figure is taken the weight saved for each E-3A aircraft would be on the order of 880 lbs.

This weight savings of approximately 30% is based on conservative design estimates with state-of-the-art flat cable and components. It must be re-emphasized that flat cable is at a disadvantage due to the lack of developed components. Also, the weight that will be saved by reduced shielding usage is not reflected in this study. It is anticipated that flat cable weight savings can be enhanced to at least 40%, and possibly 50%, with relatively minimal investments in component development.

FIGURE 3.6.1.1

EXAMPLE REPLACEMENT

HARNESS WEIGHT SUMMARY

| HARNESS CURRENT RATING, D. C. AMPS | HARNESS WEIGHT, LBS | | | | | |
|---|---|---|---|---|---|---|
| | METAL AIRCRAFT | | | COMPOSITE AIRCRAFT | | |
| | FCC | ROUND | % CHANGE | FCC | ROUND | % CHANGE |
| 278 | 20.7 | 27.4 | +24.5 | 42.0 | 52.7 | +20.3 |
| 74 | 7.0 | 9.9 | +29.3 | 14.5 | 22.3 | +35.0 |
| 16.7 | 12.9 | 13.9 | +7.2 | 16.1 | 17.1 | +5.8 |
| 3.7 | 1.29 | .92 | -40.2 | 2.08 | 1.99 | -4.5 |

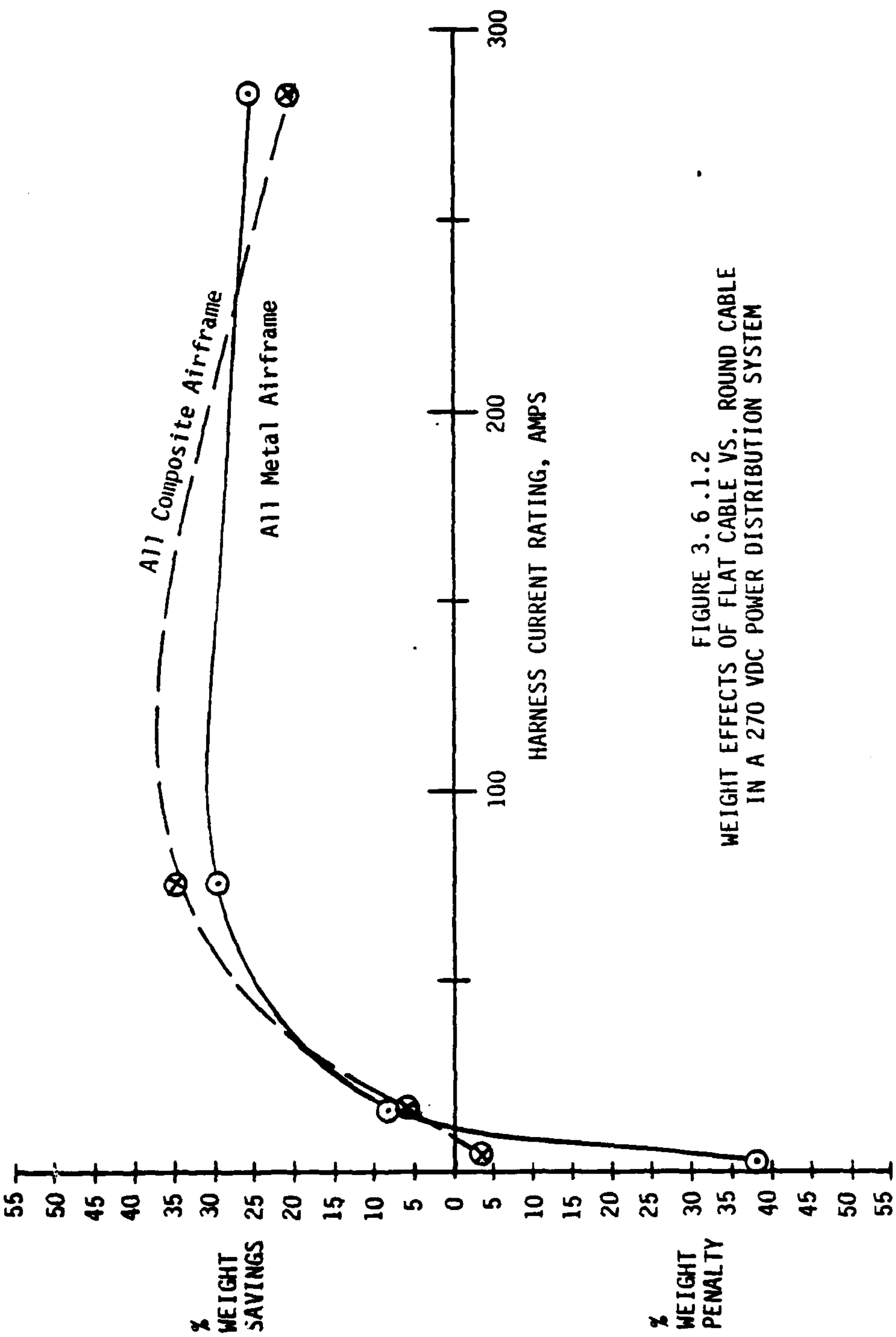



FIGURE 3.6.1.2
WEIGHT EFFECTS OF FLAT CABLE VS. ROUND CABLE
IN A 270 VDC POWER DISTRIBUTION SYSTEM

FIGURE 3.6.1.3

EXISTING 115/200 VAC SYSTEM WEIGHTS
(INCLUDING WIRING, CONNECTORS,
SPLICES, CLAMPS & SUPPORTS)

| HARNESS DESIGNATION | WEIGHT, LBS |
|---|---|
| W0294<br>W0322 | 78.25 |
| W0844 | 16.53 |
| W2343 | 14.4 (estimate) |
| W0708 | 3.66 |

### 3.6.2 Harness Reliability Comparisons

Reliability analyses usually involve a statistical treatment of available failure data on the equipment being analyzed. Due to the infancy of flat power cable, there is no failure data available.

Reliability predictions were performed using MIL-HDBK-217C. The calculations can be reviewed in Appendix D, and a summary of these results can be seen in Table 3.6.2.1.

For comparison purposes, available failure data for the E3-A was examined. Due to the relatively low failure rate of aircraft interconnects hardware, extensive records of interconnects failures are not available. The records that are kept are comprised of broad general grouping of interconnects hardware rather than data on each individual harness.

It was desired to pick a rough service environment for the chosen data group. The reasoning for this was to provide an upper limit for the failure rate predictions, i.e., a worst case comparison. Of the available E-3A data groupings, the engine area was considered to be the roughest environment, due to high temperature, high vibration and frequent maintenance activity on the engines.

This data group, work unit code (WUC) 42AZO, is shown in Table 3.6.2.2.

TABLE 3.6.2.1 Reliability Analysis - Failure Rate Predictions Using MIL-HDBK-217C for Flat Cable Versus Round Wire in Metal and Composite Airframes

| HARNESS CURRENT RATING, AMPS | CONDUCTOR GEOMETRY | METAL AIRFRAME FAILURES/$10^6$ HRS DUE TO | | | COMPOSITE AIRFRAME FAILURES/$10^6$ HRS DUE TO | | |
|---|---|---|---|---|---|---|---|
| | | CONNECTORS | CRIMPS AND TERMINALS | TOTAL* | CONNECTORS | CRIMPS AND TERMINALS | TOTAL* |
| 277.8 | Round | .129 | .025 | .154 | .175 | .050 | .225 |
| | Flat | .129 | .0333 | .162 | .175 | .0666 | .242 |
| 74.0 | Round | .090 | .00832 | .098 | .1224 | .0166 | .139 |
| | Flat | .090 | .0125 | .102 | .1224 | .025 | .147 |
| 16.7 | Round | .118 | .0125 | .130 | .118 | .0125 | .130 |
| | Flat | .118 | .0333 | .151 | .118 | .0333 | .151 |
| 3.7 | Round | .0864 | .00642 | .093 | .118 | .0125 | .130 |
| | Flat | .0864 | .0166 | .103 | .118 | .0333 | .151 |

*Failure Rate of the Conductor is Not Covered by MIL-HDBK 217C

TABLE 3.6.2.2

RELIABILITY AND MAINTENANCE
DATA FOR ENGINE CONNECTORS
(WUC 42AZ0) (1/77 TO 12/77)

| Total Connector Failures | # Of Devices Per Work Unit Code | Average Maintenance Manhours Per Failure |
|---|---|---|
| 68 | 40 | 3.61 |

The following is the operational statistics on the E-3A from 1/77 to 12/77

| | |
|---|---|
| No. Acft. | 17 |
| Flying Hrs. | 30948 |
| Flt Hours/Sortie | 7.08 |
| Flt Hours/Landing | 2.39 |
| Utilization | 67.42 (Flying Hrs/Acft/Month) |

Total connector failures includes incidental damage, support hardware failures and equipment operation failures. Only equipment operation failures are covered by MIL-HDBK 217C. For comparison to MIL-HDBK-217C, the total number of connector failures had to be sanitized as follows:

SANITIZED FAILURES = All failures - incidental damage, loose bolt-nut-screw, missing safety wire, etc.

The results are as follows:

Unsanitized Failures = 68
Sanitized Failures = 4

The calculation of the average sanitized connector failure rate is as follows:

$$\frac{4 \text{ Failures}}{30948 \text{ Flight Hrs}} \quad \frac{\text{WUC 42AZO}}{40 \text{ Connectors}} \quad \frac{10^6 \text{ Flt Hrs}}{17 \text{ Aircraft}}$$

= 0.190 Failures per connector per $10^6$ Flight Hours

Unsanitized Failure Rate =

3.23 Failures per Connector per $10^6$ Flight Hours

The sanitized failure rate for WUC 42AZO, engine connectors, is only approximately double the predicted failure rates given in Table 3.6.2.1 This is due to the worst case comparison mentioned earlier in this section.

Data similar to that given in Table 3.6.2.2 is available for the engine wiring, but it would be extremely difficult to reduce the data to a meaningful number for individual wires. A figure sometimes used to indicate the significant failure rate for individual wires has been stated to be .003 failures/$10^9$ flight hours (taken from a recent feasibility study similar to this one).

It is reasoned that the relatively low failure rates of aircraft wiring is due to the passive and benign nature of the service that wires are intended for. Since the sanitized failure rate of connectors consists of only connector operation failures, it seems likely that a sanitized failure rate for wires would be low. However, an unsanitized failure rate (including incidental damage) for wires might not be so low, as wires are subject to abrasion from nearby equipment, abuse resulting from personnel traffic or other activity near the wiring, being struck by projectiles, etc.

It is assumed that the ratio of unsanitized failures to sanitized failures

for round wiring would be equal to the same ratio for connectors:

For connectors,

$$\frac{\text{Unsanitized Failures}}{\text{Sanitized Failures}} = \frac{68}{4} = 17.0$$

Therefore, for wires

(Unsanitized Failure Rate) = (17.0) (Sanitized Failure Rate)

or

$$\begin{array}{l}\text{Unsanitized Failure} \\ \text{Rate of Wires}\end{array} = (17.0)(0.003)$$

$= .051$ Failures per Round Wire per $10^9$ Flight Hours

For the flat cables under consideration in this study, it seems likely that the flat cable would be more susceptible to incidental damage from projectiles such as drill bits, flying rocks, falling hardware or tools, etc., due to the broader profile of the flat cable and an inflexibility in the plane of conductor width. Assuming that the frequency of a cable being accidentally struck is a function of the surface (or target) area, then the frequency of flat cable strikes would be 6.9 times greater. The inflexibility of the flat cable would more often result in significant damage than with round wire, which could rebound from a projectile.

For the purposes of a fair evaluation, assume that this inflexibility would increase the significant damage rate by a factor of five. Thus for flat cables, the unsanitized falure rate would be

$$(.051)(6.9)(5) = 1.76 \text{ Flat Cable Failures}/10^9 \text{ Hrs}$$

In summary, although flat cable failures would be more frequent than round

wire failures, the impact on the overall harness failure rate would be negligible due to the much higher failure rate of connectors. This fact will be demonstrated in terms of dollars in section 3.6.3. The final failure rate predictions for the example harnesses are shown in Table 3.6.2.3.

TABLE 3.6.2.3 Final Failure Rate Predictions for Flat Cable and Round Wire Harnesses

| HARNESS CURRENT RATING, AMPS | CONDUCTOR GEOMETRY | METAL AIRFRAME FAILURES/$10^6$ HRS DUE TO | | | COMPOSITE AIRFRAME FAILURES/$10^6$ HRS DUE TO | | |
|---|---|---|---|---|---|---|---|
| | | CONNECTORS, CRIMPS AND TERMINALS | WIRING | TOTAL | CONNECTORS CRIMPS AND TERMINALS | WIRING | TOTAL |
| -277.8 | Round | .154 | .000051 | .154 | .225 | .000102 | .225 |
| | Flat | .162 | .0018 | .164 | .242 | .0036 | .246 |
| 74.0 | Round | .098 | .000051 | .098 | .139 | .000102 | .139 |
| | Flat | .102 | .0018 | .104 | .147 | .0036 | .151 |
| 16.7 | Round | .130 | .000102 | .130 | .130 | .000102 | .130 |
| | Flat | .151 | .0036 | .155 | .151 | .0036 | .155 |
| 3.7 | Round | .093 | .000051 | .093 | .130 | .000102 | .130 |
| | Flat | .103 | .0018 | .105 | .151 | .0036 | .155 |

### 3.6.3 Maintenance Comparisons

Maintenance cost figures for the round wire harnesses can be calculated from the failure rate and maintenance manhours per failure data in the reliability section of this report.

However, for the flat cable harnesses which have been designed, the average maintenance manhours per failure figure for round wire may not be accurate when applied to flat cable failure repair.

The following tables illustrate the causes of the failures on the subject aircraft interconnects hardware listed in the reliability section of this report.

Table 3.6.3.1

Causes of Failure and Percent of Total Failures
Due to Each Cause for 21 Reported Wiring Failures
on the Subject Aircraft.

| Cause: | % Due to: |
|---|---|
| Broken or Damaged Conductor | 19.0 |
| Chapped, Frayed, Cracked, or Worn Insulation | 28.6 |
| Loosened Support | 4.8 |
| Improper Maintenance Procedures | 47.6 |

Table 3.6.3.2

Causes of Failure and Percent of Total Failures
Due to Each Cause for 68 Reported Connector Failures
on the Subject Aircraft.

| Cause: | % Due to: |
|---|---|
| Loose or Missing Support Hardware | 64.7 |
| Loose or Improperly Mated Connector | 29.4 |
| Contacts Defective | 2.9 |
| Dirt or Other Foreign Matter in Connector | 1.4 |

Of the causes listed, the only failure type where maintenance procedures would be significantly different between flat and round cable is damage to the conductor itself. This amounts to 19% of all wire failures. Current practice for conductor failures almost always requires a removal/reinstallation procedure.

The 19% figure for percent of wire failures due to conductor damage will be assumed constant for flat versus round conductors.

The decision to remove and replace a harness for repairs rather than in-place repairs is based on two factors:

a. Accessibility

(1) Limited work space due to surrounding structures.

(2) Sleeving and shielding, when present, limit the

accessibility of the insulated conductor.

b. Ability to use required tools and procedures aboard a fueled aircraft.

The current procedure for round wire conductor damage repairs is as follows:

i. Unclamp and free terminals or connectors from their mating points.

ii. Free the conductor from its support clamps.

iii. Lift out, drop or pull the conductor through routing passages and dispatch to a repair facility workshop.

iv. At the shop, the expandible, braided sleeving and shielding (if present) is pulled back to expose the damaged area. Depending on the type and extent of damage, the conductor is spliced and reinsulated, the shield and sleeve replaced, and the cable returned for reinstallation.

This procedure could not be used for flat cable for two reasons:

c. The stiffness of the solid conductors and the permanent folds used for routing would make complete harness extraction difficult in most cases.

d. The creases would tend to bind or block the sleeving or shielding during pull back.

Flat cable maintenance tasks on the conductor would require either repair procedures that could be performed aboard a fueled aircraft or a complete renewal of the harness when the damaged cable is cut out of position.

It is considered possible and reasonable to develop repair methods and tools for in-place repairs of flat cable. The decision to either repair a harness or to renew it should be based on the cost of developing the required methods and tools versus the savings to be achieved by repairing rather than renewing.

Estimates of the times required for in-place repairs as well as complete harness renewal can be reviewed in Appendix E, as well as cost estimates for maintenance procedures on the high and medium ampacity harnesses. The results of these estimates can be reviewed in Table 3.6.3.3

Table 3.6.3.2 Summary of Maintenance Comparative Analysis - Maintenance Costs/$10^5$ Flight Hours

| | Harness Current Rating | Cost, $/$10^5$ Hr | |
|---|---|---|---|
| | | Metal Airframe | Composite Airframe |
| Round Wire Repair | 277.8<br>74.0 | 6.3<br>4.0 | 9.0<br>5.6 |
| Flat Cable Renewal | 277.8<br>74.0 | 6.4<br>4.1 | 9.3<br>5.8 |
| Flat Cable In-Place Repairs* | 277.8<br>74.0 | 6.9<br>4.4 | 9.2<br>5.7 |

*Does not include cost of required tools and methods.

In summary, the very low failure rate of wires as compared to connection interfaces result in negligible maintenance costs due to the wires. Even with

a very generous increase in the flat cable failure rate compared to the round wire failure rate, the maintenance costs for connectors, crimps and terminals remains the controlling factor. The higher costs for repairing a flat cable harness in-place when the conductor is damaged would be of questionable value even without the costs of methods and tools development. Therefore, when flat cable conductor damage is encountered, it would be most cost effective to cut out the entire harness and replace it with a new one.

The higher maintenance costs for flat cable harnesses is due to the additional interfaces at the transition terminal block. With the development of a one piece transition connector, the maintenance costs for flat cable harnesses should be equal to the round wire harness maintenance costs.

### 3.6.4 HARNESS COST COMPARISONS

#### 3.6.4.1 Cost Analysis

This analysis includes an assessment of costs of acquisition and ownership for a flat cable power distribution system. The analysis conducted and the data provided are baselined to the existing wire harness assemblies W0322, W0294, W0844, W0708 and W2343.

This cost analysis includes acquisition cost elements involved in producing flat cable harnesses in a modern production and manufacturing facility.

A starting point in a life-cycle-cost analysis is the identification of a cost structure appropriate for the task and related objectives. A cost breakdown structure was assembled and iterated throughout this effort. This report addresses three major elements of a typical program as a cost analysis framework. These are Production Set-Up, Manufacturing, and Operation and Support.

In order to address the subject of life-cycle-cost in a realistic manner an important fact must be recognized by the reader. The present contract is a "paper study" only, where no hardware is developed and no shop or manufacturing experience can be established. Consequently, the production set-up, manufacturing and operation and support elements included in this report are predictions based on the concept of a low production quantity of flat cable power harnesses similar to that of the baseline wire harnesses.

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FEASIBILITY STUDY OF A 270V DC FLAT CABLE AIRCRAFT ELECTRICAL P--ETC(U)
JAN 82 M J MUSGA, R J RINEHART N62269-81-C-0231
UNCLASSIFIED D182-10816-1 NADC-82023-60 NL

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This report will not attempt to predict with accuracy the cost variations of the current flat cable technology nor the inflationary impacts of the future on flat cable versus round wire materials. These effects could, however, be applied to the base of the information contained in the report.

Production set-up costs, the non-recurring costs, are based on the concept of a low production rate facility for yielding economy from current equipment and methods. Equipment costs are based on quotes or estimates of purchase prices or upon engineering estimates.

Manufacturing costs, the recurring costs, relate primarily to the flow of tasks and processes which dictate the greatest share of the cost of a harness assembly.

Production and manufacturing cost estimates are based on a survey and analysis of company experience in producing various quantities of wire harness assemblies for both military and commercial programs.

The approach used was to correlate this experience with similar tasks related to production/manufacture of a flat cable harness assembly and then to provide engineering estimates of unique equipment, tasks or processes. These results are supported by harness assembly cost model estimates and by gross level cost factors established from direct experience on past and on-going company programs.

Operation and support costs analyses are based on history data on the E-3A

aircraft and an extensive history on four Navy aircraft, the S-3A, E-2C, P-3C and EC-130G and Q.

### 3.6.4.2 Cost Breakdown Structure

A carefully planned cost breakdown structure is a basic and vital tool in Design-to-Life-Cycle-Cost efforts. The cost breakdown structure should provide cost tracking for what, who and when. That is, what the hardware or software elements are, who contributes to tasks related to each element, and, the timeframe established for accomplishing the tasks. A properly structured cost breakdown structure will also provide visibility for improvements in cost and performance and the structure for a useful history base. A simplfied baseline cost breakdown structure was developed for this effort and utilized as a guidline in collecting and analyzing cost data. This structure was reduced to those elements of major impact. Some elements were eliminated or altered to avoid an unreasonable expense of effort or to take advantage of available data or established techniques in assessing or predicting costs. The outline of this analysis reflects the final iteration.

### 3.6.4.3 Production Set-Up Cost Analysis

The production set-up cost analysis will take into account all the non-recurring costs for a facility to manufacture flat cable power distribution harnesses. It is based on the concept of a E-3A airplane being converted to 270V DC flat cable distribution system. The areas which are addressed and the results of the cost analysis are as follows:

| | |
|---|---|
| Production Equipment Cost = | 145,000 |
| Production Facilities Cost = | 230,000 |
| Production Training Cost = | 25,000 |
| Total Non-Recurring Cost = | $400,000 |

(1) Basic Equipment Requirements

A cost analysis for production set-up costs can be based on a number of concepts. Production rates for the cost analysis will determine the quantity and degree of automation of the equipment to be used. For this cost analysis production rates will be equaled to the E-3A aircraft. The type of facility modification will also effect the cost analysis. The following are the choices which are available.

| | | |
|---|---|---|
| Production Quantity: | Low | 300 harness/mo |
| | Medium | 1500 harness/mo |
| | High | 3000 harness/mo |

Facility Modification:

New Facility

Expand Existing Facility

The concept which will be used for this cost analysis, and which is felt to be the most probable initial production of flat cable power harnesses will be a modification of an existing harness manufacturing facility with a low

production rate.

The broad scope of this analysis is intended to provide an information base for visibility and hence the estimates provided herein are of a rough order-of-magnitude nature. These estimates do not include contractor fees or escalation due to inflation. Escalation factors on purchased items is presently estimated at 4 percent per quarter. Production equipment cost is shown in Appendix F Table 1 and indicated an initial non-recurring investment of $145,000.

(2) Facilities Requirements

Basic facilities accommodations will consist of normal lighting, ventilation and heating with either normal height or raised ceilings. Air conditioning is required in the potting, dry and cure areas along with possible exhaust ducts. Approximately ten high capacity outlets need to be provided. Some rough order-of-magnitude cost-estimating for facilities are given below:

Refurbished Facility
Without air conditioning - $45.00 per sq. ft.
With air conditioning - $60.00 per sq. ft.

These refurbishments include heat/ventilation/lighting, standard electrical outlets and air drops.

The production facilities cost is shown in Appendix F, Table 2 and indicates an initial non-recurring investment of $230,000.

(3) Training Requirements

Two separate courses are recommended for personnel for production of flat cable power harnesses.

One course is a 16 hour familiarization course which presents concepts and relationships governing the application of flat cable technology. This course will also emphasize critical care, handling, test and troubshooting aspects of real hardware and will exercise student knowledge through mental and paper exercises as well as through elementary tasks involving real hardware as training devices. Some laboratory, manufacturing and test equipment will also be demonstrated with student participation. This course will be designed for supervisors, engineers, quality inspectors, and others whose basic understanding is important to the evaluation and decision making processes related to successful development and application of flat cable technology.

The second course is a 24 hour certification course design for manufacturing personnel and technicians involved in development, test, installation and handling. This course will have the same general content as the 16 hour course with less emphasis on concepts and relationships governing the applications of flat cable technology. This course will also have greater emphasis applied to the critical care, handling, test and troubleshooting aspects and will make extensive use of hardware training devices for developing and verifying student understanding and physical skills.

The production training costs are shown in Appendix F, Table 3, and indicate a total of approximately $25,000.

3.6.4.4 Manufacturing Cost Analysis

(1) Process Flow

In manufacturing, process flow manhours is the dominant factor related to manufacturing costs. The tasks, steps and related timelines for the baseline wire harness assembly have been estimated by finance and by mechanical and industrial engineering specialists. Similar estimates have then been applied to a planned flat cable harness assembly process with the addition of unique steps and processes. Tables of task steps and associated timelines are provided in Appendix F, Tables 5 through 9.

(2) Production Materials Cost Estimates

The materials cost estimates for the flat cable harness assembly and the round wire harness assembly are shown in Appendix F. These estimates have been established from Finance records of actual costs, vendor quotes where available, and engineering estimates based on previous experience.

(3) Installation Cost Estimates

Estimates for the installation of the harnesses under consideration are shown in Appendix F, in Tables 10 through 13. The estimates for the round wire are based on established E-3A costs. The flat cable time estimates were derived

by visualizing the motions and installation steps which must be performed to install the harness. Since hardware is not available rough estimates have been made assuming the technicians installing the harness are experienced in flat cable handling procedures.

3.6.4.5 Operation and Support Cost Analysis

(1) Historical Data Base

A history base for estimating installation, operation, and support costs for flat cable harnesses is extremely limited. A history base for wire harnesses in military and commercial aircraft is also relatively limited.

(2) Operations Analysis and Predictions

The E-3A aircraft which contains the baseline wire harness assembly contains approximately 1,000 wire harnesses or cables with a weight of 5,685 pounds. These are categorized as follows:

| | |
|---|---|
| Power distribution systems | 2,929 pounds |
| Flight essential systems | 262 pounds |
| Mission essential systems | 2,358 pounds |
| Instruments | 136 pounds |
| Total | 5,685 pounds |

For comparison and estimation purposes assume that flat cable

harnesses/cables are used for all power distribution applications. Further, assume that a weight savings of 30% is achieved by replacing round wire power harnesses with the flat cable harnesses. This results in a total weight savings of 880 pounds per aircraft. A current estimate for fuel consumed during the E-3A's lifetime is approximately 495 $ of fuel per pound of aircraft. Flat cable usage would therefore save 435,600 dollars worth of fuel per aircraft lifetime.

In referring to this fuel savings figure, an important fact must be recognized by the reader. This figure is for a military aircraft, where the weight saved might be replaced with additional fuel. In this instance, the use of flat cable would increase the mission range of the aircraft. The numbers given above are intended for comparison purposes only, as shown in Table 3.6.4.6.1.

(3) Spares, Repair Parts, and Inventory Estimates

In view of the relatively low rate of failure of wire harness/cable assemblies the general spares policy for the E-3A aircraft has not included spare harness/ cable assemblies. Spare parts and materials are maintained as standard supply items by the Air Force.

The spare parts and repair material cost estimates are based on the cost formula outlined in NELC report NPS 55JS 76031 and the recommended inventory replenishment factor.

Cost = (Inventory replenishment factor)

X (Unit production cost)

X (Quantity of Equipment)

= (0.05) x (any material + labor to build) x (1) = $/harness

Inventory management costs are likewise estimated based upon the cost formula outlined in NELC report NPS55Js 76031.

(Inventory Cost Management) =

50 $/Harness (Typical)

(4) Special Support and Test Equipment and Tools

1. Equipment and Tools

| | | | |
|---|---|---|---|
| a. | Pin insertion and removal tools | 10 | 3,000 |
| b. | Crimping equipment terminal (1 power) (1 manual) | 2 ea | 5,250 |
| c. | Crimping equipment splicing (1 power) (1 manual) | 2 ea | 5,250 |

2. Support Equiment Maintenance

Cost = (maintenance factor) x (cost of peculiar support equipment) = (0.10)(13,500) = 1,350

3. Special support and test equipment and tools costs including maintenance 14,850

(5) Training

1. Maintenance Personnel Training = 10 students/ 1 instructor/1 week course (refer to report NPS-550s 76031 and apply cost escalation) $10,000

2. Instructor Training = (Refer to report NPS-550s 76031 and apply cost escalation) $10,000

### 3.6.4.6 High Ampacity Life Cycle Cost Summary

These costs have been spread over a ten year lifetime and averaged into a per harness cost at a production rate of 300 harnesses per month.

A life cycle cost summary is shown for the high ampacity run as Table 3.6.4.6.1.

TABLE 3.6.4.6.1
LIFE CYCLE COST SUMMARY
FOR HIGH AMPACITY (277.8A) RUN

| | METAL AIRFRAME | | COMPOSITE AIRFRAME | |
|---|---|---|---|---|
| | FLAT | ROUND | FLAT | ROUND |
| COMPONENTS PURCHASE $/HARNESS | 277.4 | 286.0 | 446.0 | 495.2 |
| HARNESS ASSEMBLY $/HARNESS | 233.1 | 216.7 | 293.1 | 283.3 |
| PRODUCTION INSTALLATION $/HARNESS | 231.7 | 190.0 | 290.0 | 235.0 |
| MAINTENANCE COSTS $/100K HRS | 6.4 | 6.3 | 9.3 | 9.0 |
| LIFETIME FUEL DEBT * | 10250.0 | 13563.0 | 20790.0 | 26087.0 |
| | | | | |
| SUM | 10998.6 | 14262.0 | 21828.4 | 27109.5 |

* BASED ON 495 $/LB LIFETIME JET FUEL CONSUMPTION

# 4.0 Flat Cable Design Criteria

## 4.1 General Discussion

The chief advantages of stacked flat cable are, in order of decreasing importance:

a. A greater area for heat transfer. This allows the use of smaller wire cross sectional area for the same steady state current compared to round wire. It also improves high temperature performance and fault current response time .

b. Reduced inductance and increased capacitance. These parameters lower the tendency for radio frequency interference (RFI) to couple to and be emitted from the harness, and eliminates the high frequency coupling of electromagnetic pulse (EMP) and lightning induced transients. The net effect is a reduction in shielding effectiveness requirements.

c. A lower profile for areas where routing space is most available in two dimensions (length and width,but not height), and a greater flexibility in one plane where small radius turns are required.

The chief disadvantages are, in order of decreasing importance:

d. Tendency for crack propagation through the solid conductor.

e. Broader profile for incidental damage from projectiles.

f. Inflexibility opposite the plane of conductor width. This fact, coupled with the solid conductor, results in some added contortions for routing that are not required for round wire.

4.2 Required Parameters for Flat Cable Design

Before proceeding with the design of a flat cable harness, the following parameters must be known:

1. The maximum ambient temperature of the harness environment.

2. The maximum steady state current that the conductor is required to carry. If this value is below 10.0 amperes, flat cable is not recommended and other design guides should be used.

3. The magnitude and duration of fault transients to be encountered in the harness lifetime.

4. The environment in which the conductor must serve, i.e., pressurized or unpressurized, expected vibration levels, chemicals such as battery acid, jet fuel, hydraulic fluid, etc., which may be present,

radiation levels, and so on.

5. The maximum voltage drop permitted between the source and the load.

6. The length and routing (number of twists and turns) of the harness.

7. The degree of heat confinement that will be experienced during operation. If adjacent structures are more than 6.0 inches away, or less than 6.0 inches away but no more than 10.0 inches in length per 5 feet of run, this confinement can be considered negligible.

### 4.3 Conductor Material Selection - Copper Versus Aluminum Conductors

At first glance, the use of aluminum conductors seems quite attractive from a weight savings standpoint. The conductivity of aluminum is only 63% of the conductivity of copper. However, the density of aluminum is 30% that of copper. This means that for given conditions of current, temperature and voltage drop, an aluminum conductor must have 59% greater cross-section than copper conductor, but the aluminum conductor would weigh 52% less.

However, there are other considerations which diminish the benefits of using aluminum:

1. For the equivalent aluminum conductor above, the increase in cross section results in an increase in total insulation, which decreases the weight savings.

2. The mechanical strength of aluminum creates problems when an attempt is made to utilize it in small gauge sizes.

3. To improve mechanical strength and flexibility of aluminum, it is usually alloyed with small amounts of other metals. However, the operating temperature of these alloys is limited to 350$^{o}$F due to premature aging at higher temperatures.

4. It is usually desired to utilize both copper and aluminum wires in a given structure. This means that the two must make electrical contact at some point. Being dissimilar metals, galvanic corrosion and differential thermal expansion are problems. Splice fittings are available that employ chemical inhibitors; however, they present a weight and space penalty over regular fittings.

5. When exposed to the atmosphere, the outermost molecular layers of aluminum rapidly form a high resistance oxide film. If a compression or crimp type connection is made, it will satisfactorily crush through this oxide film. However, if the contact faces are intermittently exposed to the atmosphere, the oxide film will creep into the joint and result in excessive and damaging heat evolution at the contact interface. Any electrical contact with aluminum must remain gas tight, and under no circumstances should a quick-disconnect contact be made directly to aluminum.

In addition to these general considerations, there are some specific considerations when considering aluminum versus copper in flat conductor

cable.

1. The requirements for greater cross-section when using aluminum results in a larger surface area for heat transfer. This change does not significantly affect temperature rise in the case of round wire, but it is significant with flat cable. Thus, the weight of aluminum in flat cable is reduced even further over the weight savings of aluminum versus copper in round conductors.

2. The mechanical strength problems with aluminum become even more critical due to the thinness of flat conductor. Aluminum has less ductility than copper. Breakage would become a problem in areas of tight routing, frequent flexing, and vibration.

In summary, aluminum conductor is recommended in flat cable power runs above 100 amps where routing bends and flexing are infrequent and vibration and temperature levels would be low.

For other conditions, copper would be a better choice due to the greater ductility and vibration resistance.

## 4.4 Insulation Material Selection

The selection of insulation material is one of the most important and most difficult steps in a wire harness design process.

Except in the case of aluminum conductors, the insulation is the controlling

factor for maximum conductor temperature. The temperature limit for the popular organic insulations is always less than 300°C. Any service above this temperature requires a glass or mineral inorganic insulation.

The other major factors affecting insulation selection are as follows:

a. Methods of wire manufacturing

b. Thickness requirements for dielectric strength

c. Stripability and/or pierceability

d. Environmental service conditions, i.e., abrasion, chemicals, radiation, low pressures (for outgassing and corona), etc.

The following insulations have been used to fabricate flat cables similar to those required for military aircraft applications.

a. Polyester
   Temperature rating: 105°C
   Application Method: Extrusion

b. Ethylene Tetrafluoroethylene (ETFE)
   Normal Temperature Rating: 150°C
   Temperature Rating with Radiation Post-Treatment: 200°C
   Application Method: Extrusion

c. Fluorinated Ethylene Propylene-Polyimide (FEP-PI)

Temperature Rating: 200°C

Application Method: Lamination

d. Tetra Fluoroethylene (T.F.E.)

Temperature Rating: 260°C

Application Method: Extrusion

e. Fluoroelastomeric Heat Shrinkable Tubing (F.E.H.S.T)

Temperature Rating: 200°C

Application Method: Heat Shrinking

All of the above mentioned insulations have excellent mechanical, electrical and environmental resistance properties. Some of them may demonstrate undesirable factors when used in a specific harness or application. For example, Type "E" above, F.E.H.S.T., would be relatively expensive and difficult to produce in long lengths, and would not be recommended for high volume production. However, it could be quite useful for fabrication of a limited number of test harnesses. The strengths and limitations of each insulation material must be carefully examined in respect to the specific application under consideration. Military specifications MIL-C-49059 and MIL-C-55543 may be helpful in providing similar test methods and applicable considerations.

### 4.4.1 Conductor Plating Requirements

In conjunction with insulations, another variable to be considered is plating to be used on a conductor.

Historically, plating has been used for two purposes: (1) To enhance solderability; (2) to inhibit oxidation of conductors at high temperature.

With the recent innovations in solderless connection techniques, such as crimping and wire wrapping, the solderability requirements of wires have played an ever diminishing role in the use of plating.

The second factor, inhibition of oxidation, remains a significant motivation for the use of plating.

The plating materials used most commonly are tin, silver, and nickel. Tin and silver both have moderate temperature ratings. Hence they are used primarily for solderability purposes. Nickel plating is employed on wires for high temperature application.

With flat conductor power distribution harnesses, terminations are anticipated to be crimp or compression contact styles, with no use of soldering whatsoever. The only plating requirements would be to inhibit oxidation on harnesses in high temperature areas where high resistance contacts or conductor erosion would be intolerable. The plating used would be nickel or a similar high temperature material.

Plating is for copper conductors; aluminum is not usually plated.

## 4.5 Flat Conductor Sizing

This section details the selection of the correct size of flat conductor cable for D.C. power distribution. "Correct" is defined as the smallest cable which will carry the load current without exceeding the temperature limits of the cable or the allowable voltage drop of the circuit. The size selected by these procedures is for average conditions. Under adverse conditions, such as near high temperature equipment or when the harness is in a confined space, the current rating must be decreased. This derating will be covered in later sections.

Since the chief advantage of flat conductor cable is a larger area for heat transfer, thus allowing the use of smaller conductors than with conventional round wire, it is important that the procedure in this section be followed carefully.

The use of smaller conductors with flat cable, when equivalent to round wire in terms of temperature, results in an increase in voltage drop. For most aircraft harnesses the conductor size is controlled by thermal characteristics but in some instances, such as very long runs or where allowable voltage drops are quite small, the conductor voltage drop becomes the dominant factor. Flat cable also has a voltage drop advantage over round wire for conductors with equal cross section, but this advantage is considerably milder than the increase in current capacity. In harnesses where voltage drop becomes the controlling factor, the flat cable size selected should be compared with the round wire size required for the same task and

the round wire should be used if the sizes are the same since the methodology surrounding round wire applications are well established.

4.5.1 Selèction Procedure For Flat Cable

The following parameters must be ascertained before proceeding:

1. $T_a$ - Maximum ambient temperature expected in the service environment of the harness.

2. $L_r$ - The known or estimated length of the run from the source to the load.

3. $I_l$ - The load current to be carried by the harness.

4. $A_m$ - The maximum altitude rating of the aircraft.

5. $V_m$ - The maximum voltage drop between the source and the load.

6. $N_c$ - Number of conductors, one single conductor, or two stacked conductors.

4.5.1.1 Use a wire with a temperature rating which is at least $100^{o}F$ higher than the maximum ambient temperature. Subtract the maximum ambient temperature from the actual wire rating to obtain the true temperature difference.

4.5.1.2 Refer to the appropriate figure as indicated below:

| Wiring Configuration | Conductor Material Copper | Aluminum |
|---|---|---|
| 2 stacked | Figure 4.5.2 | Figure 4.5.3 |
| 1 single | Figure 4.5.4 | Figure 4.5.5 |

Find the intersection of a vertical line through the load current, $I_l$, and a horizontal line through the true temperature difference. Read the wire size of the nearest diagonal line to the right of the intersection. Also read the current rating of this slightly larger wire at the true temperature difference. Call this rating $W_r$ and make note of the result. If the intersection is only slightly to the right of the next smaller size, this next smaller size may be used if the intersection of the load current and the smaller size diagonal line cause an increase of less than 10% in the temperature difference. If this smaller size is used, the wire rating $W_r$ is equal to the load current $I_l$. Figure 4.5.1 shows the dimensions of equivalent flat cable sizes with a width-to-thickness ratio of 150.

4.5.1.3 Figure 4.5.6 may be used for either copper or aluminum conductors in either a stacked or single configuration. Note that the lower curve is for flat cable with a cross-section equal to or less than a #6 AWG round wire, while the upper curve is for flat cable with a cross section equal to or greater than a #4 round wire.

Find the intersection of a vertical line from the design altitude rating to the appropriate curve. Move horizontally from this intersection point to the Y-axis, which will yield the derating factor required for altitude. Multiply the wire rating $W_r$ determined in paragraph 4.5.1.2 by this fraction and make note of the result.

4.5.1.4 From Figure 4.5.7 for copper (or Figure 4.5.8 for aluminum) draw a line from the maximum ambient temperature, $T_a$, on the X-axis to the appropriate curve for the conductor selected in paragraph 4.5.1.2. Move horizontally to the Y-axis to find the fraction change in current capacity for T greater than $50^{o}F$. Multiply the wire rating $W_r$ determined in paragraph 4.5.1.2 by this fraction and make note of the result.

4.5.1.5 From the initial wire rating $W_r$ determined in paragraph 4.5.1.2, subtract the result determined in paragraph 4.5.1.3 and add the result of paragraph 4.5.1.4. Call this sum $W_R$ and compare it to the load current $I_l$. If $W_R$ is not greater than or equal to $I_l$, repeat paragraphs 4.5.1.2 through 4.5.1.5 for the next larger wire.

4.5.1.6 From the appropriate figure of Figures 4.5.9 through 4.5.32 find the intersection of the line length $L_r$ and the load current $I_l$. It is permitted to interpolate voltage drop graphs if the precise conditions are not covered by the figures. This intersection must be below the line drawn for the wire size to be used. If it is not for the wire size selected thus far, increase the wire size to one whose line is just above the intersection. Please note that the voltage drops given are for single wires; in a two wire system, each wire will consume half the total allowable drop.

4.5.1.7 It is necessary for wire to be capable of carrying transient overloads without damage to the insulation. These overloads can be caused by the starting of large inductive loads or coupling of incident electromagnetic fields. Figure 4.5.33 is a graph of the allowable short time current rating

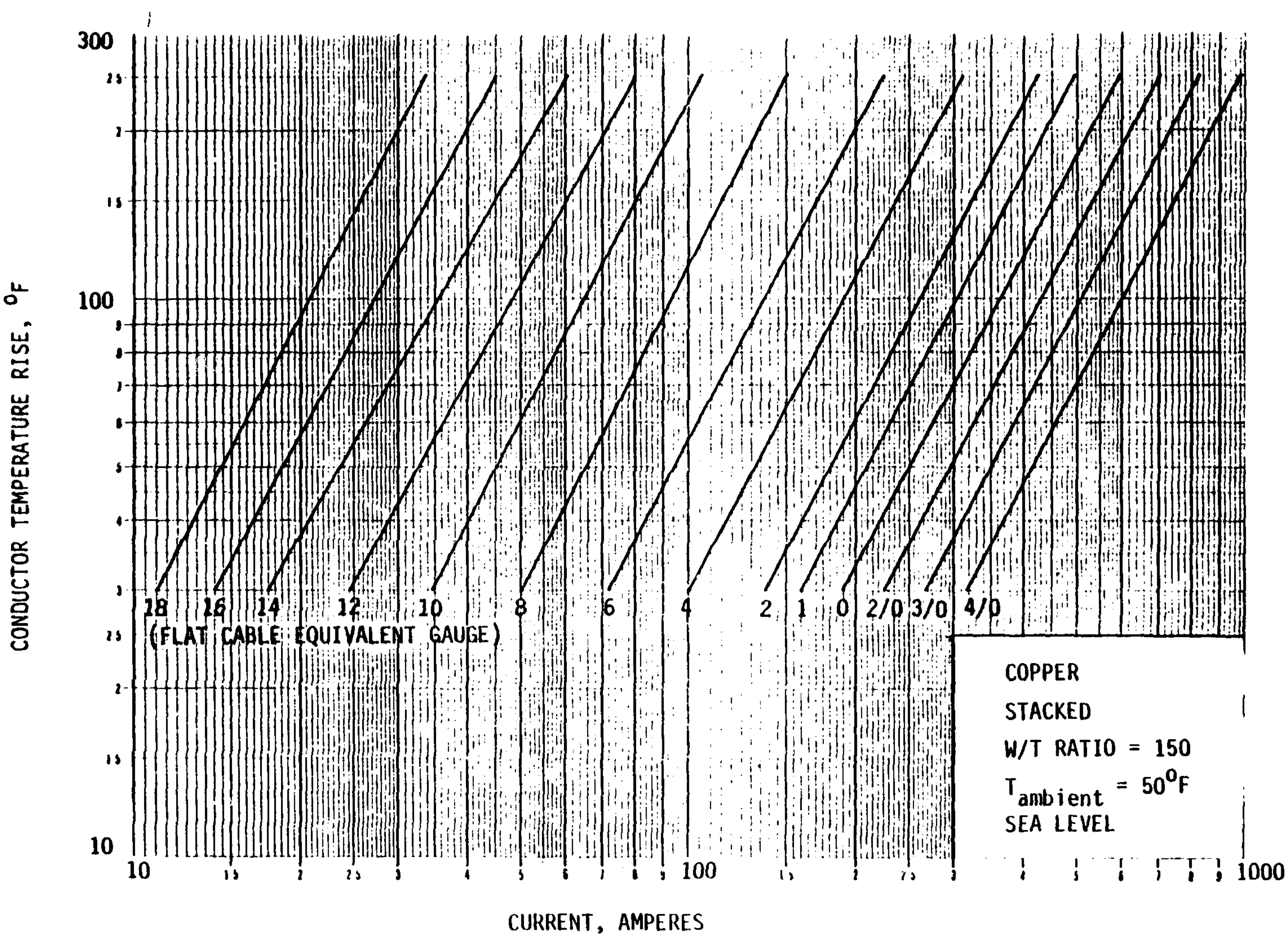
vs. transient duration time for single or stacked conductors. This graph assumes an allowable intermittent temperature rise of 85°F. By dividing the total expected transient current by the rated current of the wire size used, a per unit figure is obtained. Draw a horizontal line from the per unit current ordinate and draw a vertical line from the abscissa (expected time duration of overload). If the point of intersection of these two lines is below the curve of the wire used, it will carry the overload. If the point of intersection falls above the wire curve, a larger size wire should be used.

| Round Wire AWG # | X-Section In$^2$ | W/T = 150 | | Weight, lbs/1000' (6 MILS FEP-PI Insulation) | |
|---|---|---|---|---|---|
| | | Width In. | Thickness In. | Cu | Al |
| 20 | .000955 | 0.378 | .00252 | 7.3 | -- |
| 18 | .00149 | 0.473 | .00315 | 10.3 | -- |
| 16 | .00191 | 0.535 | .00357 | 12.5 | -- |
| 14 | .00301 | 0.672 | .00448 | 18.0 | -- |
| 12 | .00461 | 0.832 | .00554 | 25.6 | -- |
| 10 | .00735 | 1.050 | .00700 | 38.2 | -- |
| 8 | .0133 | 1.412 | .00942 | 64.5 | -- |
| 6 | .0211 | 1.779 | .01186 | 98.0 | 41.4 |
| 4 | .0335 | 2.242 | .01494 | 150.0 | 60.2 |
| 2 | .0522 | 2.798 | .01865 | 227.3 | 87.3 |
| 1 | .0642 | 3.103 | .02069 | 276.5 | 104.2 |
| 0 | .0821 | 3.509 | .02340 | 349.3 | 128.9 |
| 2/0 | .104 | 3.950 | .02633 | 437.8 | 158.7 |
| 3/0 | .131 | 4.433 | .02955 | 546.3 | 194.8 |
| 4/0 | .166 | 4.990 | .03330 | 687.0 | 241.1 |

FIGURE 4.5.1

FLAT DIMENSIONS FOR EQUIVALENT CROSS SECTION
TO CONVENTIONAL SIZE ROUND WIRES

FIGURE 4.5.2
TEMPERATURE RISE (WIRE RATING - AMBIENT)
VS. CURRENT CAPACITY VS. FLAT CABLE GAUGE SIZE

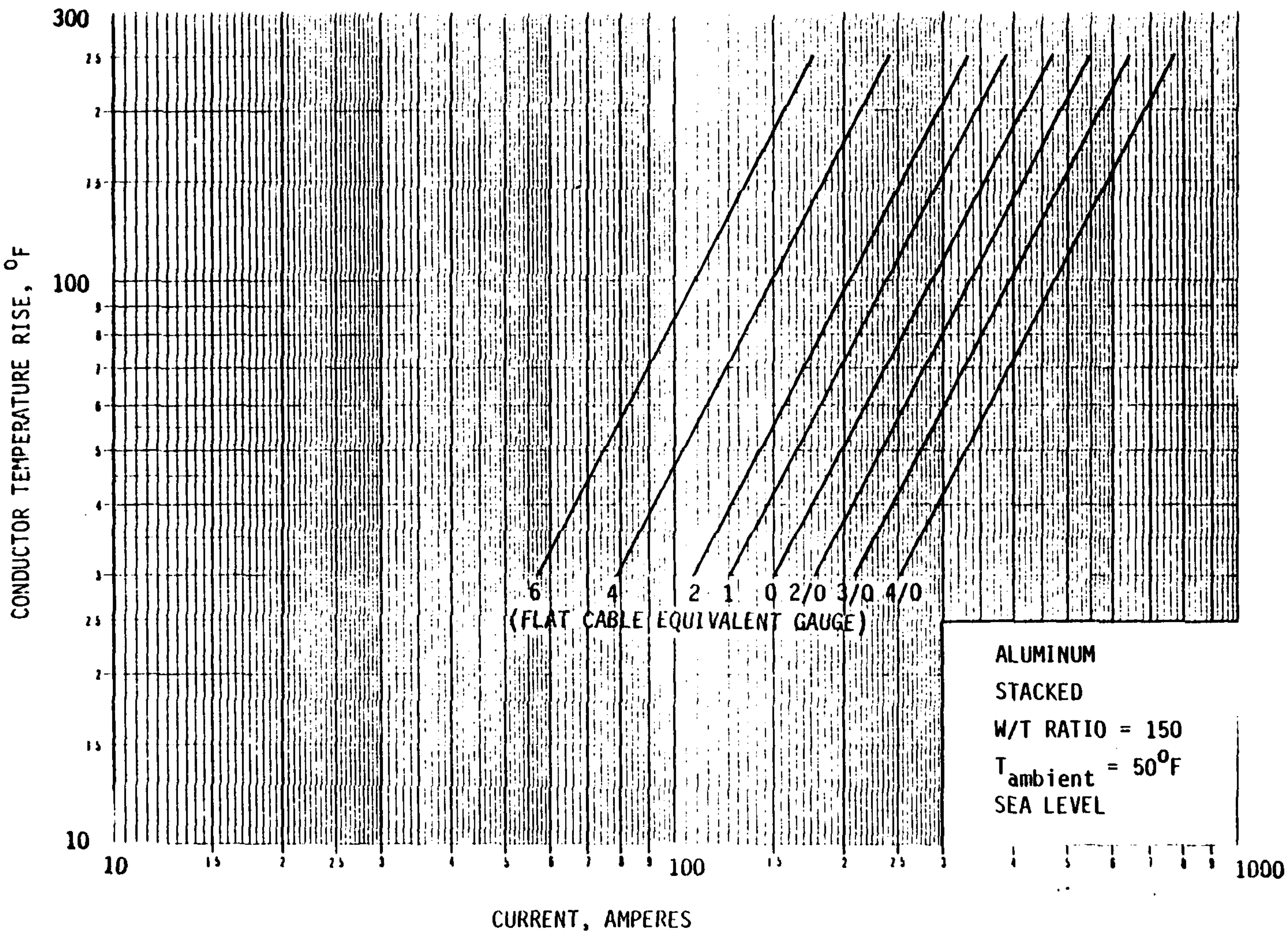



Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.3

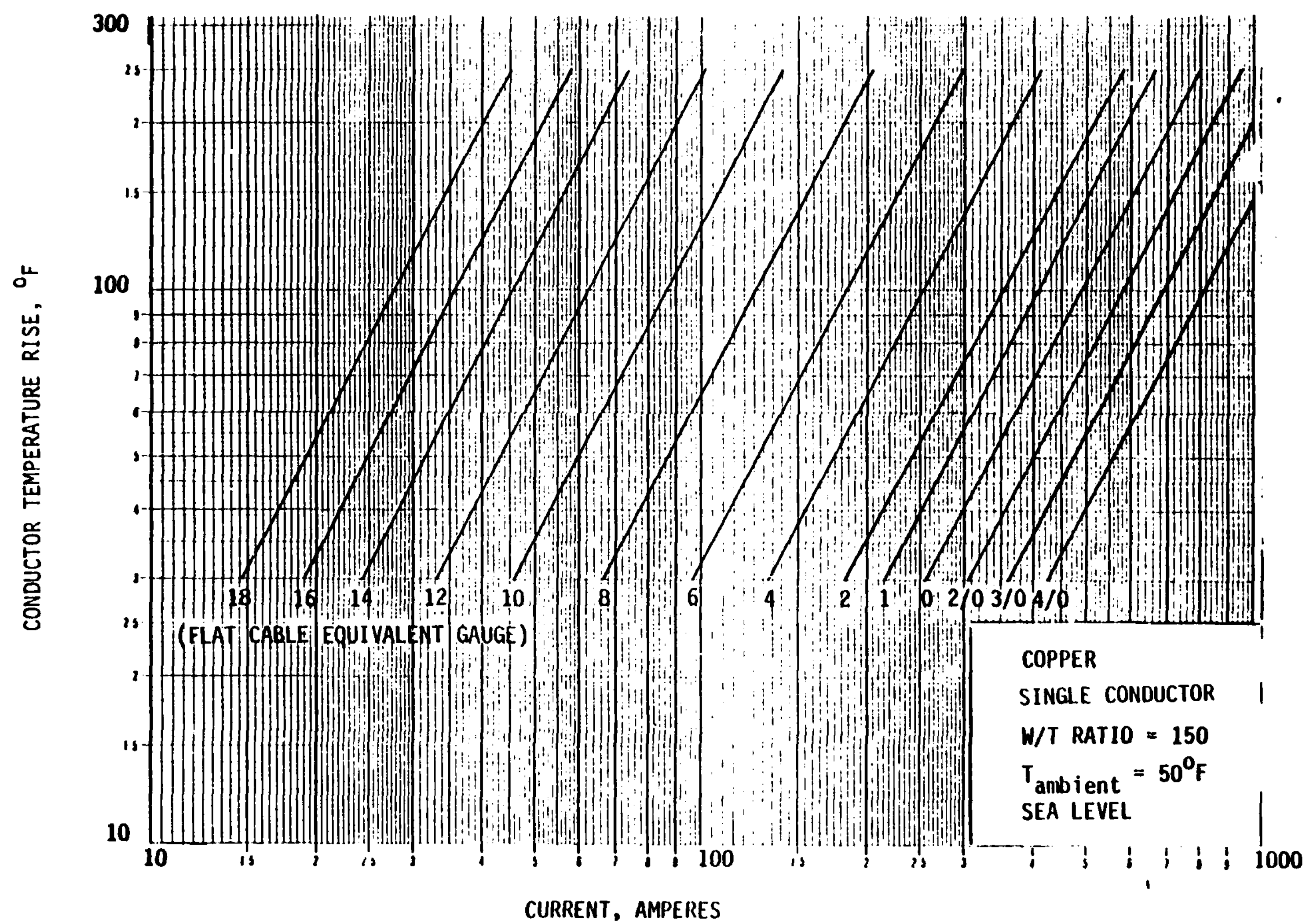
TEMPERATURE RISE (WIRE RATING - AMBIENT)

VS. CURRENT CAPACITY VS. FLAT CABLE GAUGE SIZE




Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

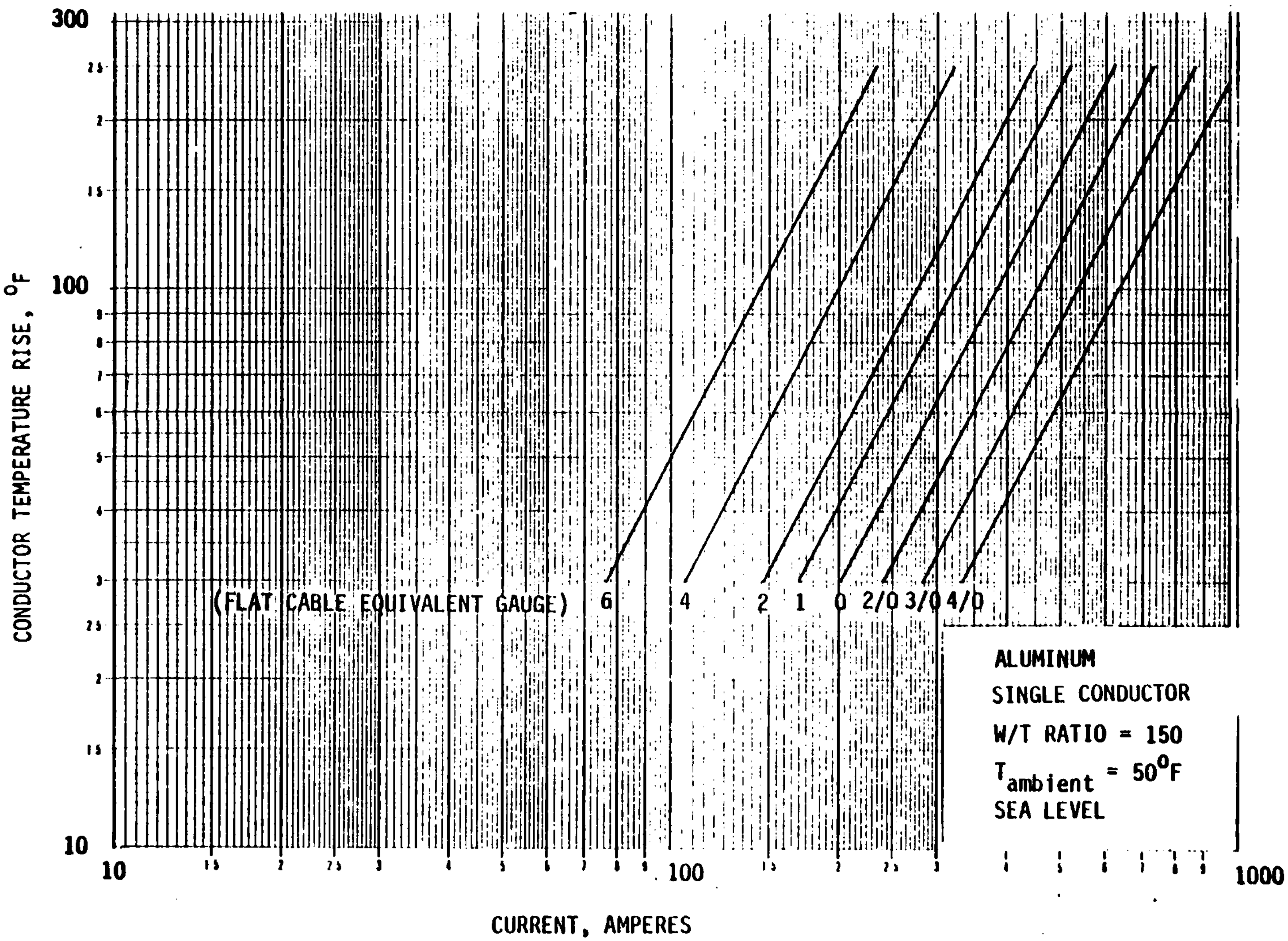
FIGURE 4.5.4
TEMPERATURE RISE (WIRE RATING - AMBIENT)
VS. CURRENT CAPACITY VS. FLAT CABLE GAUGE SIZE




**Note** hese curves are based on calculations for general ( iitions and should be used for preliminary estimat( nly.

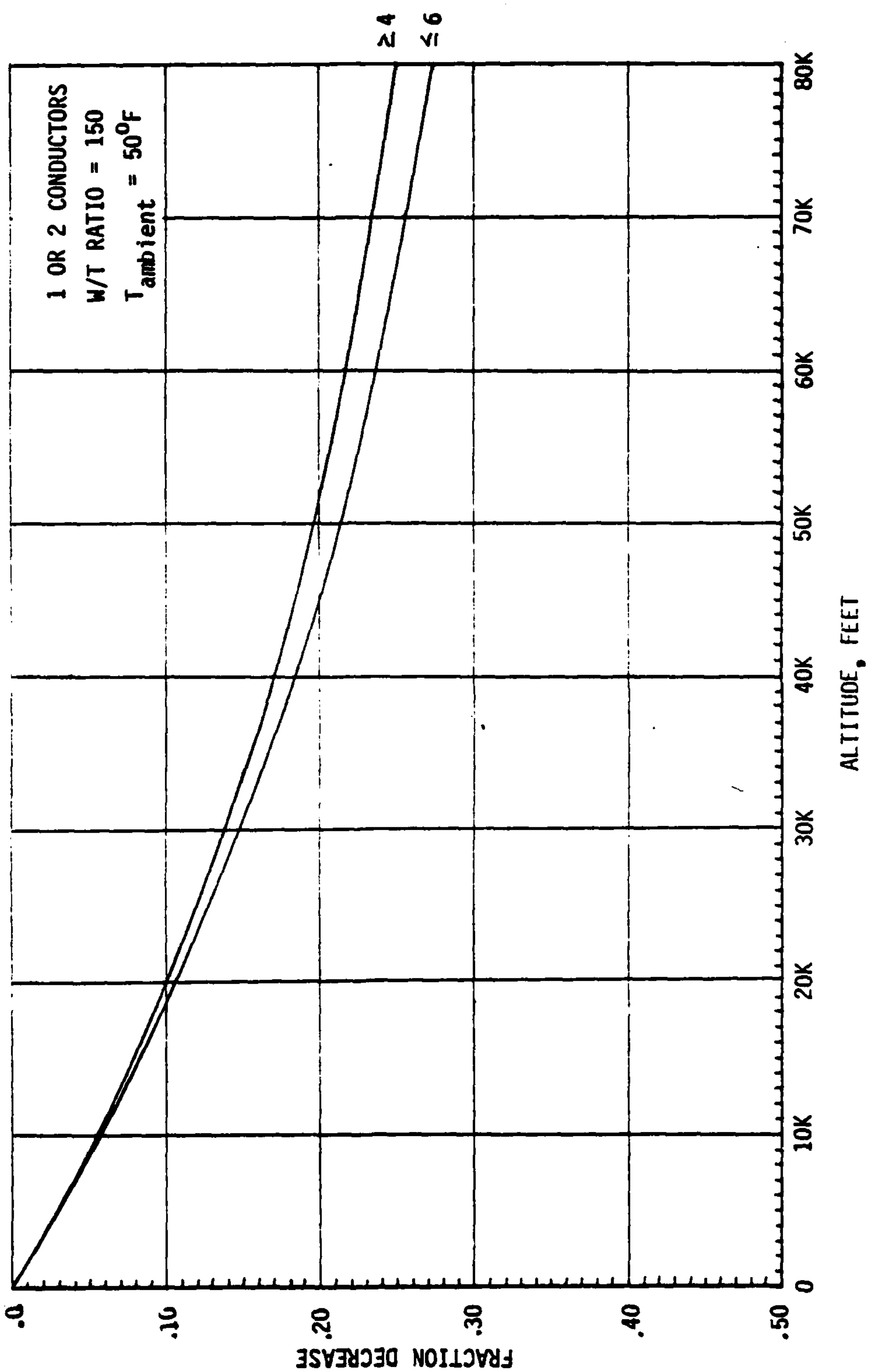
FIGURE 4.5.5

TEMPERATURE RISE (WIRE RATING - AMBIENT)
VS. CURRENT CAPACITY VS. FLAT CABLE GAUGE SIZE




Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

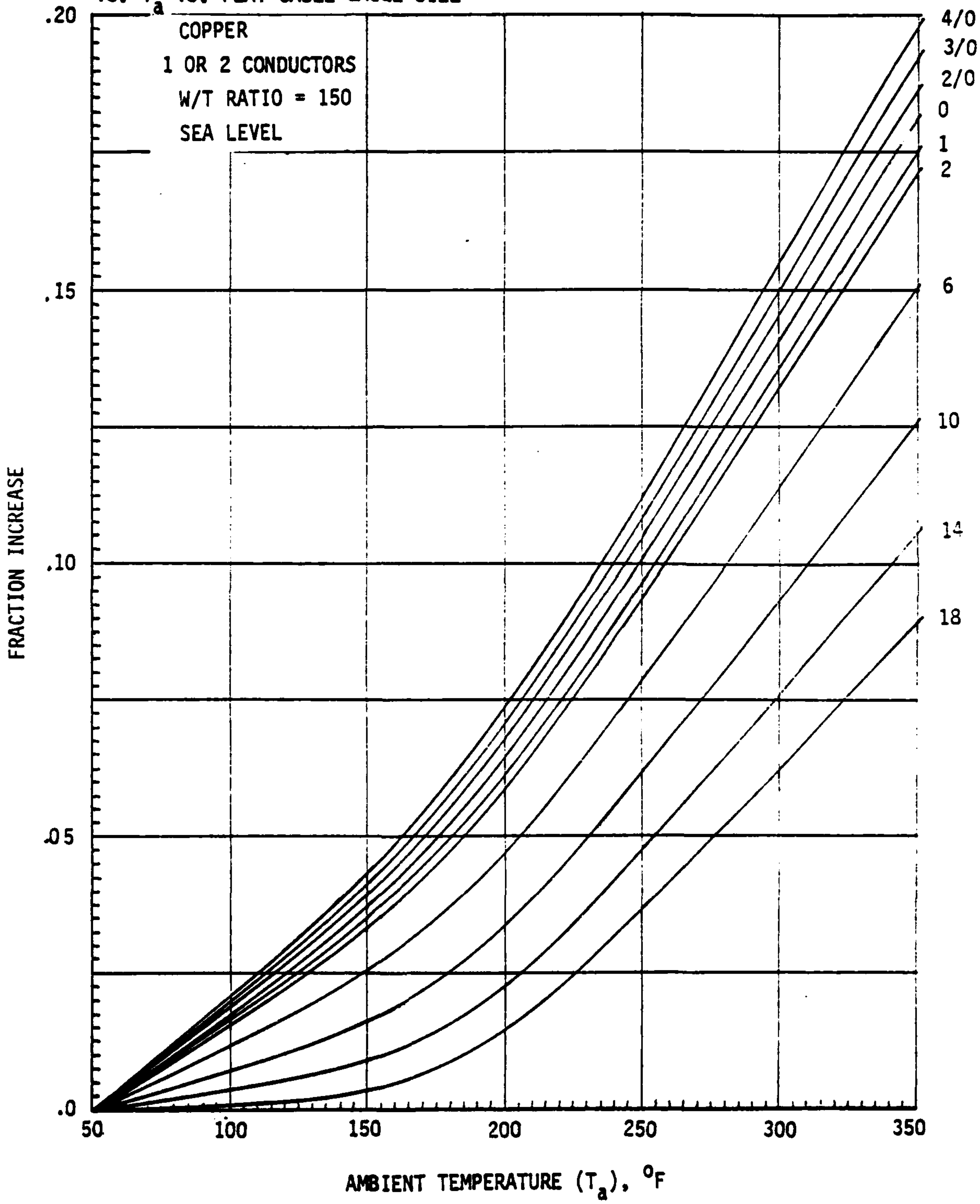
FIGURE 4.5.6
FRACTION DECREASE IN CURRENT CAPACITY
VS. ALTITUDE VS. FLAT CABLE GAUGE SIZE




Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.7

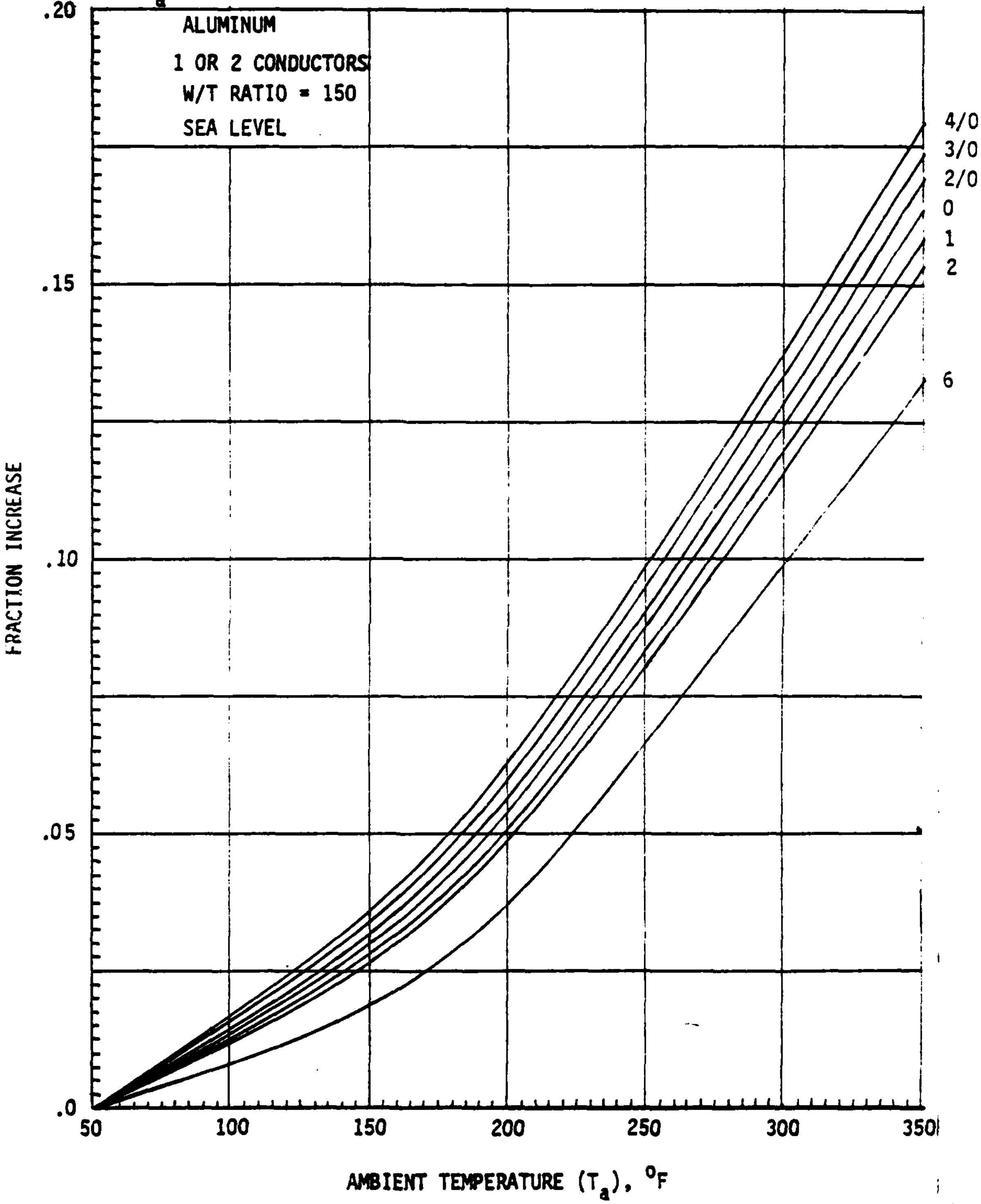
FRACTION CHANGE IN CURRENT CAPACITY FROM $T_a$ = 50 °F VS. $T_a$ VS. FLAT CABLE GAUGE SIZE




Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

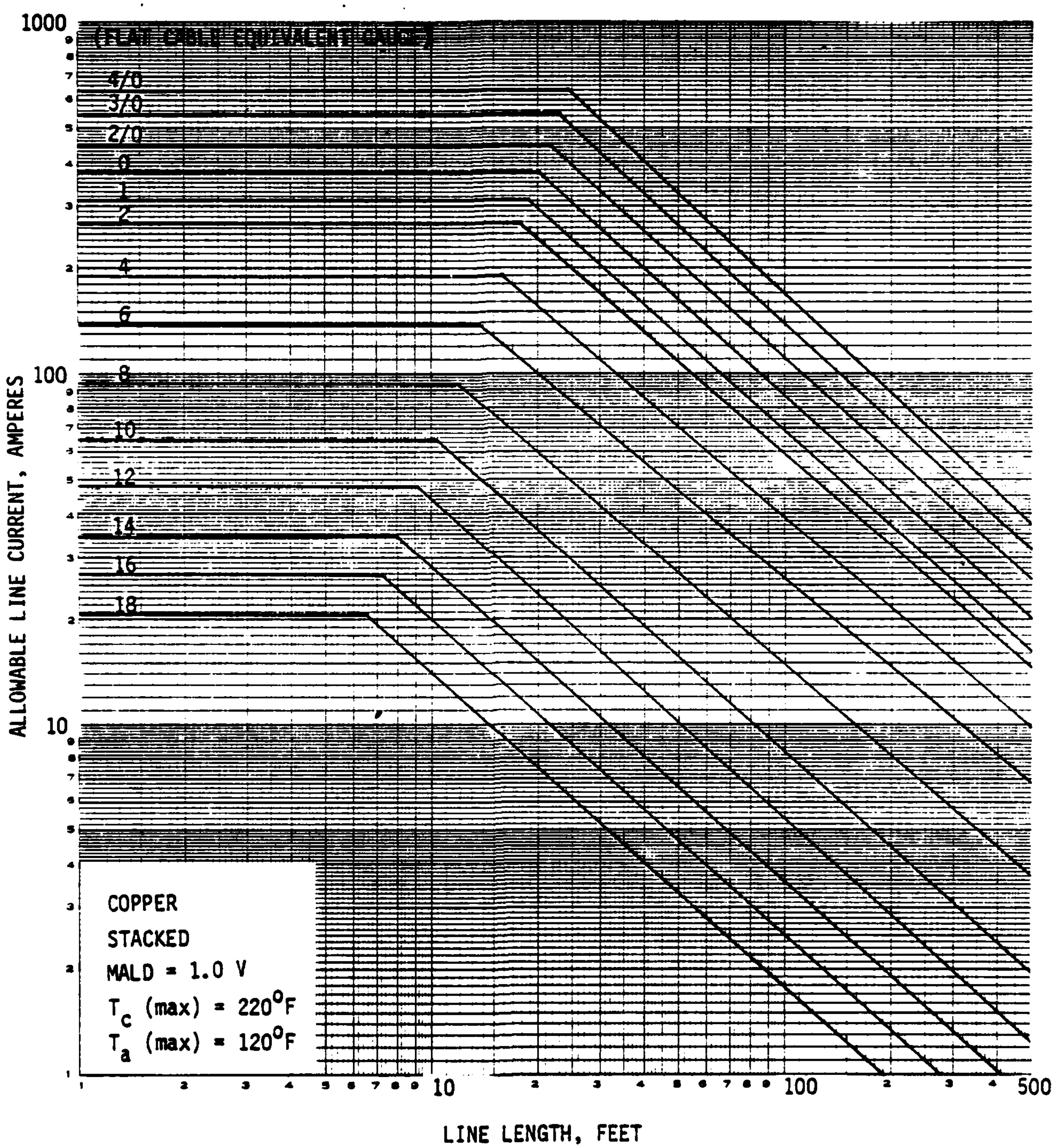
FIGURE 4.5.8

FRACTION CHANGE IN CURRENT CAPACITY FROM $T_a$ = 50 °F VS. $T_a$ VS. FLAT CABLE GAUGE SIZE



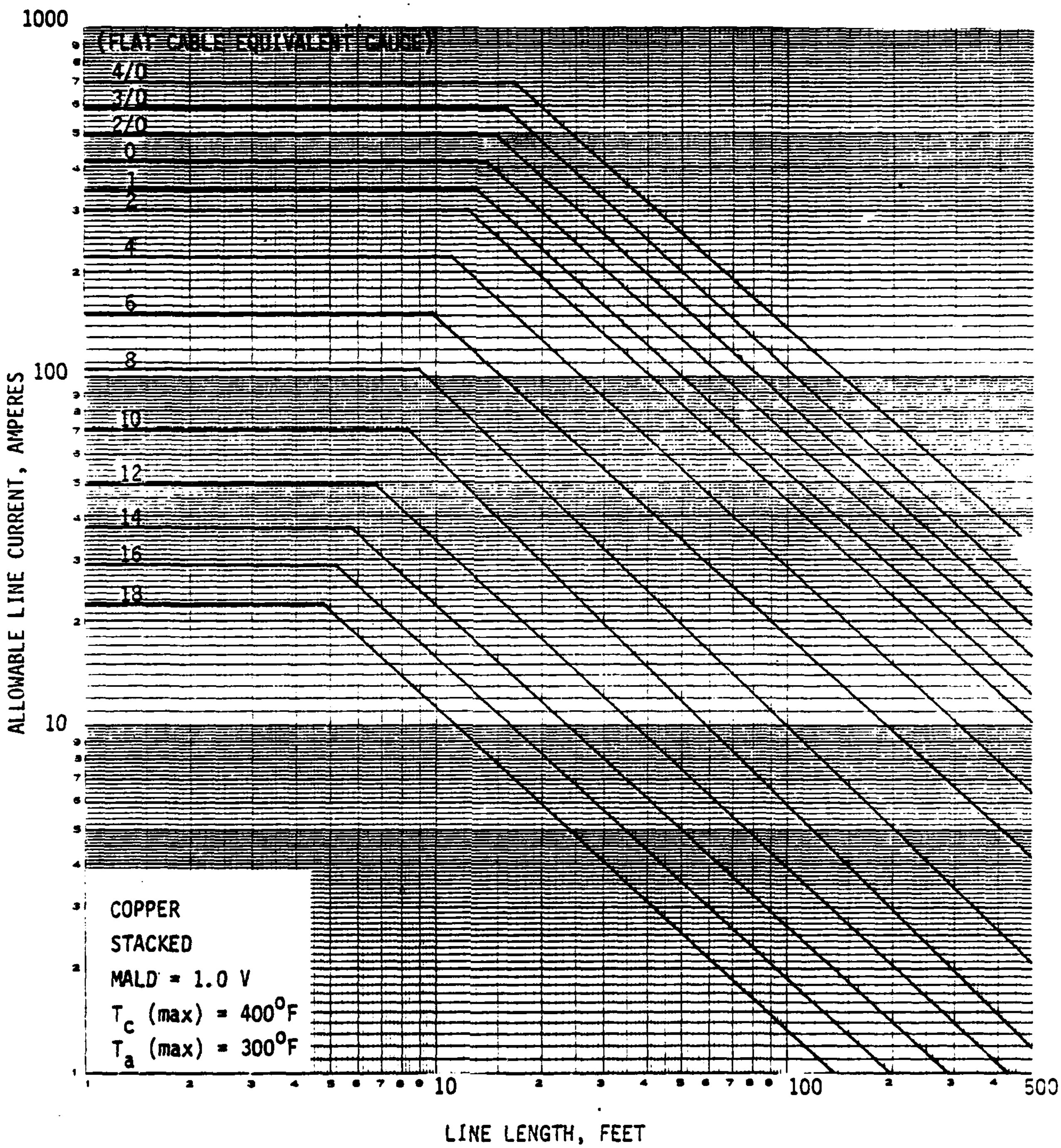

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.9
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



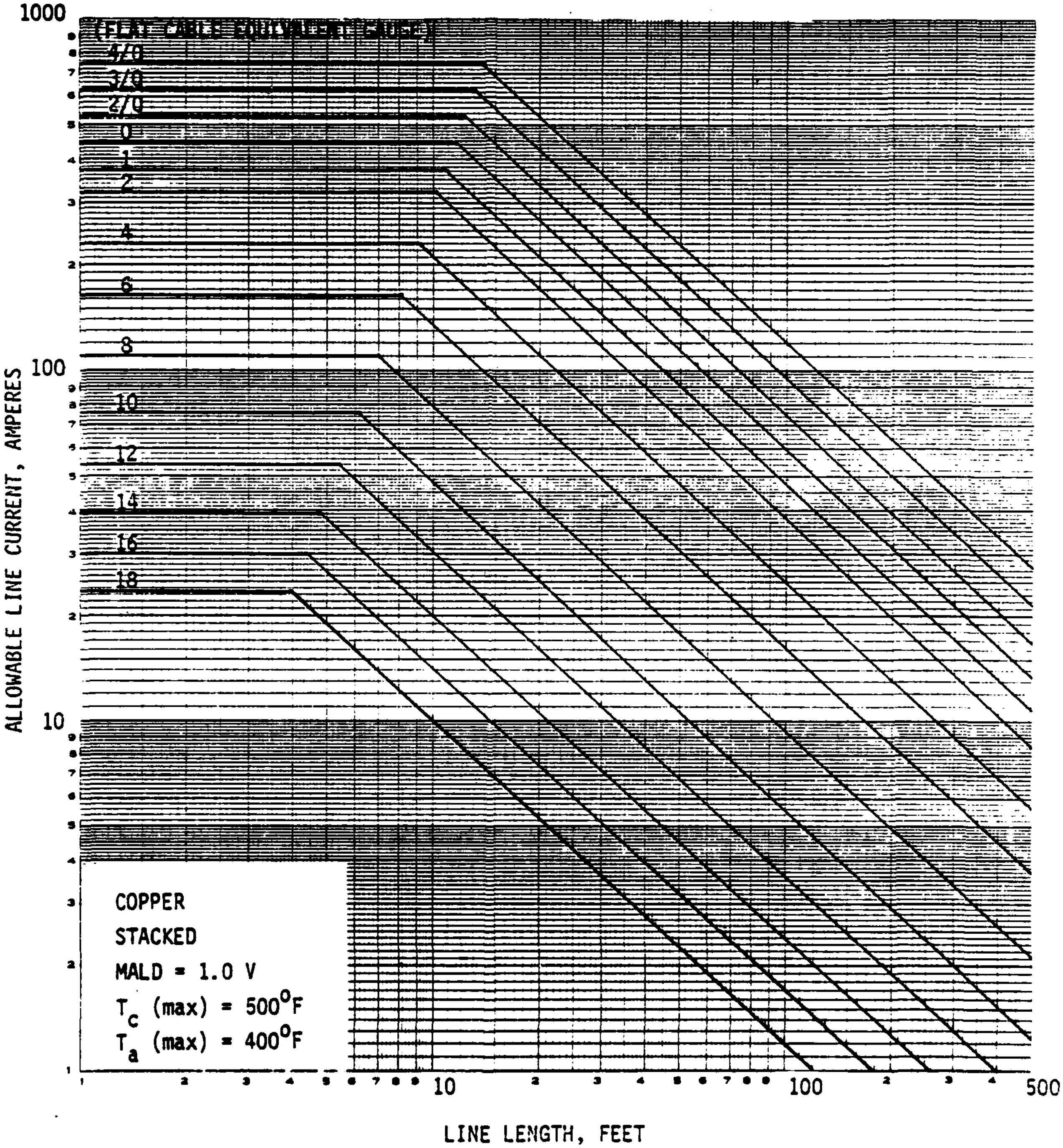

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.10
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



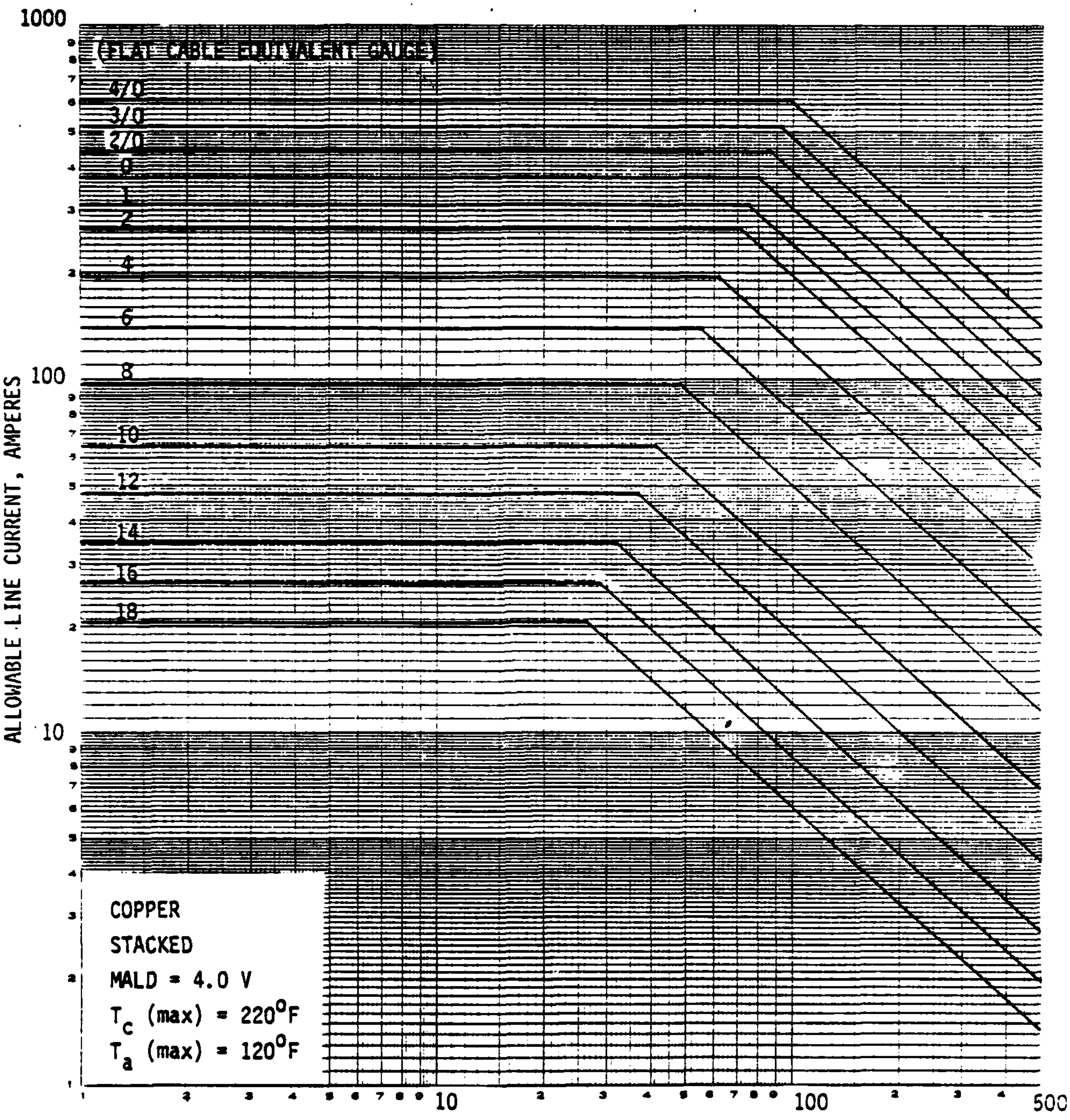

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.11
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



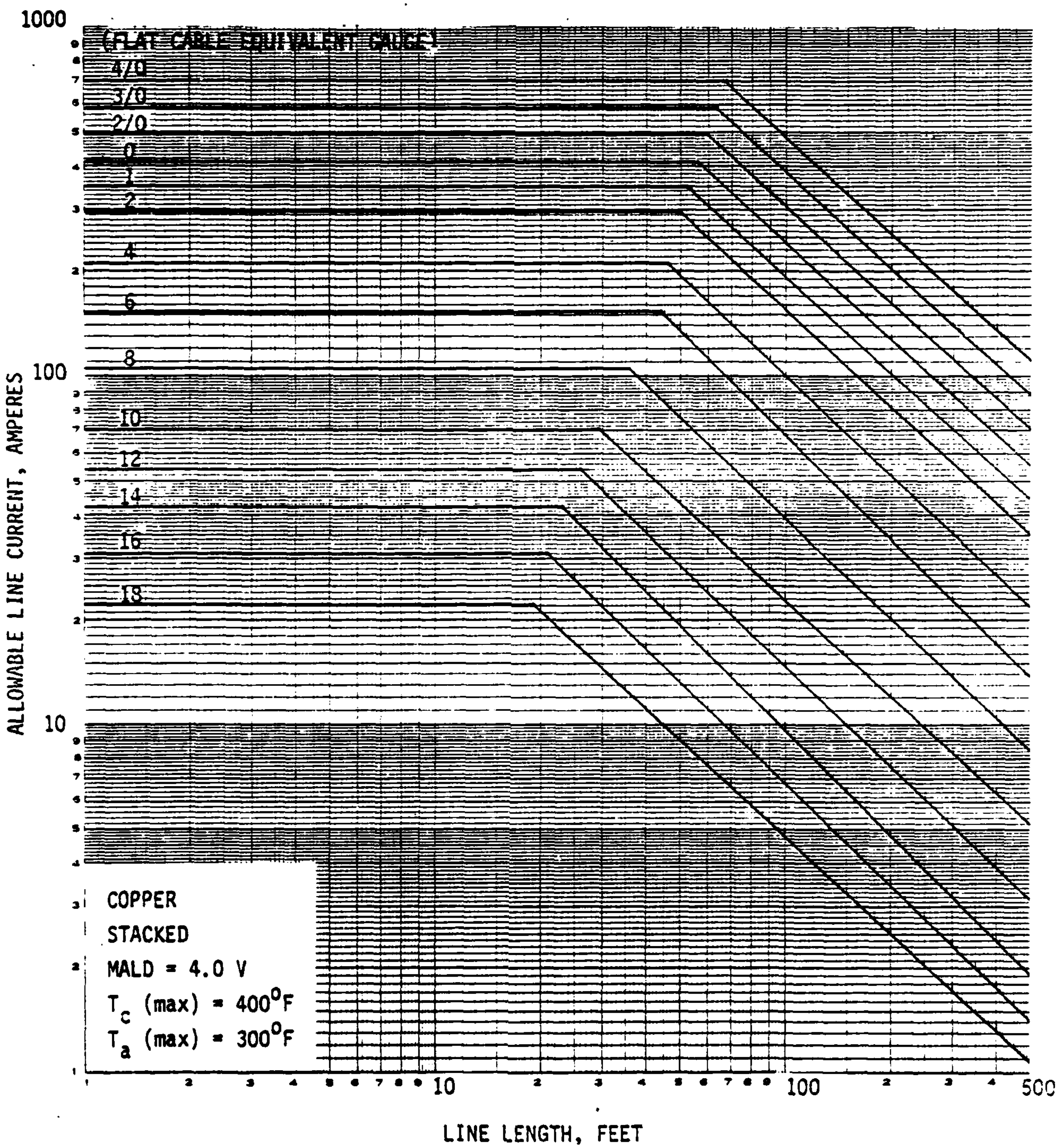

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.12
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



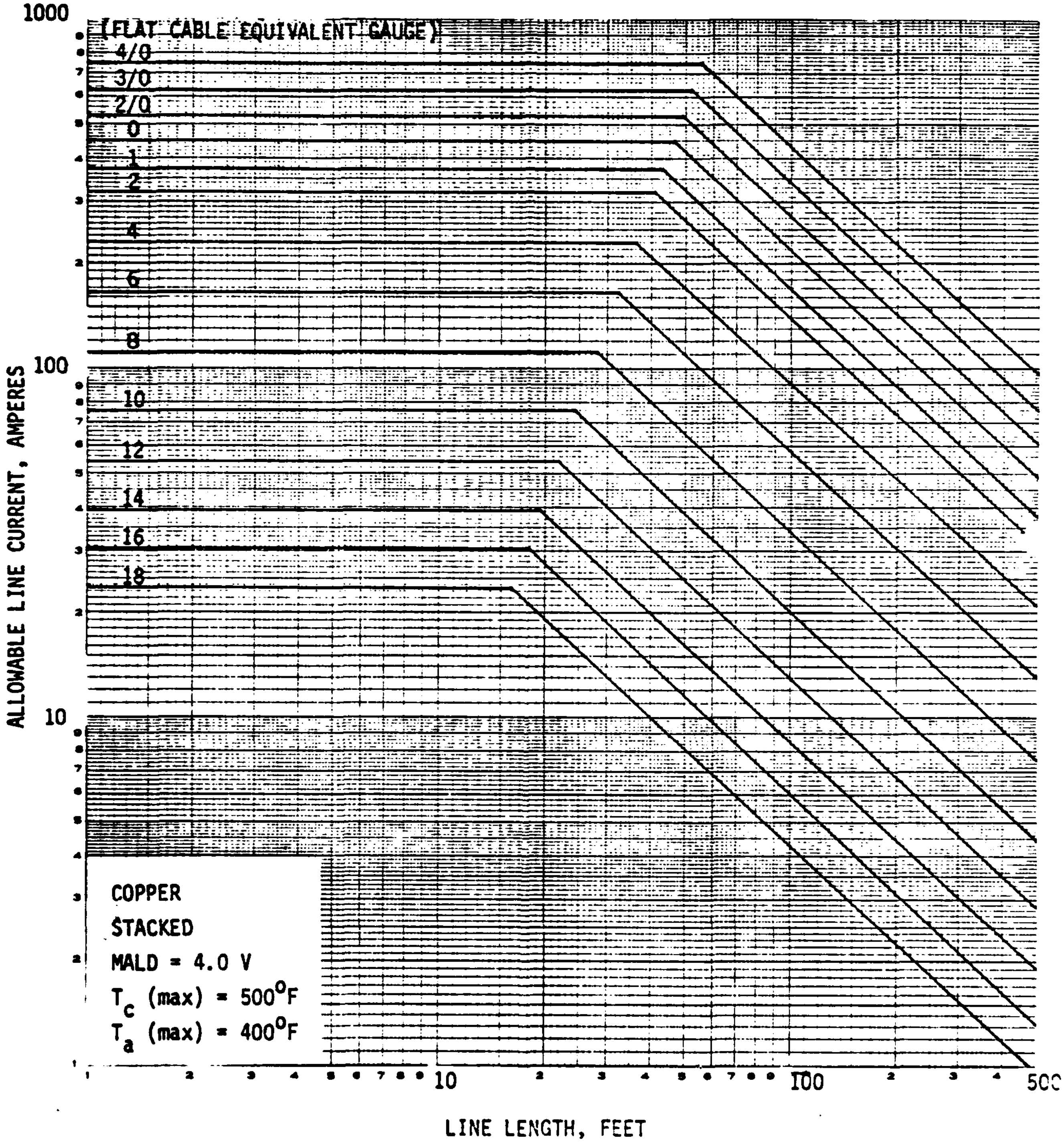

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.13
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



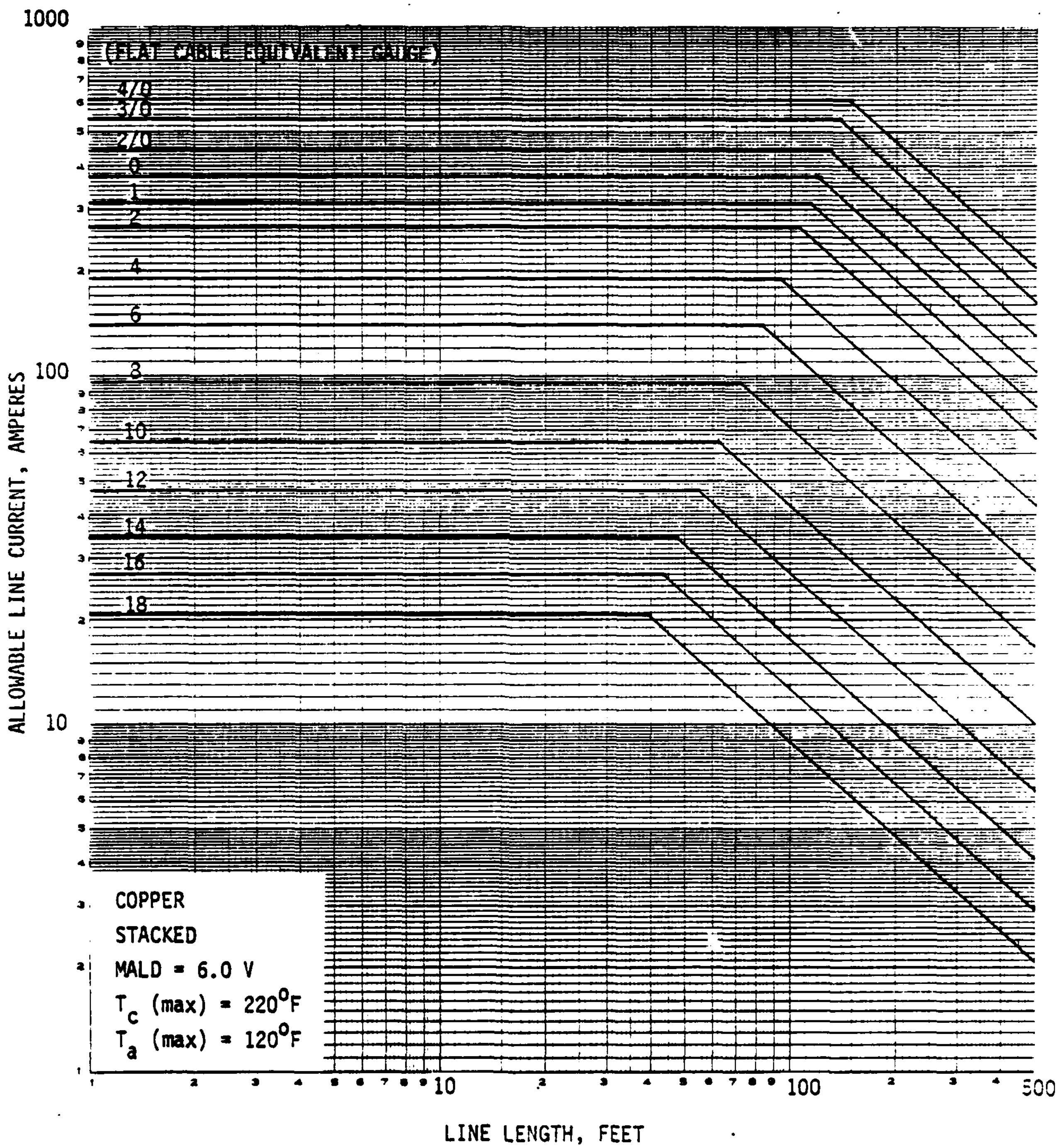

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.14
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



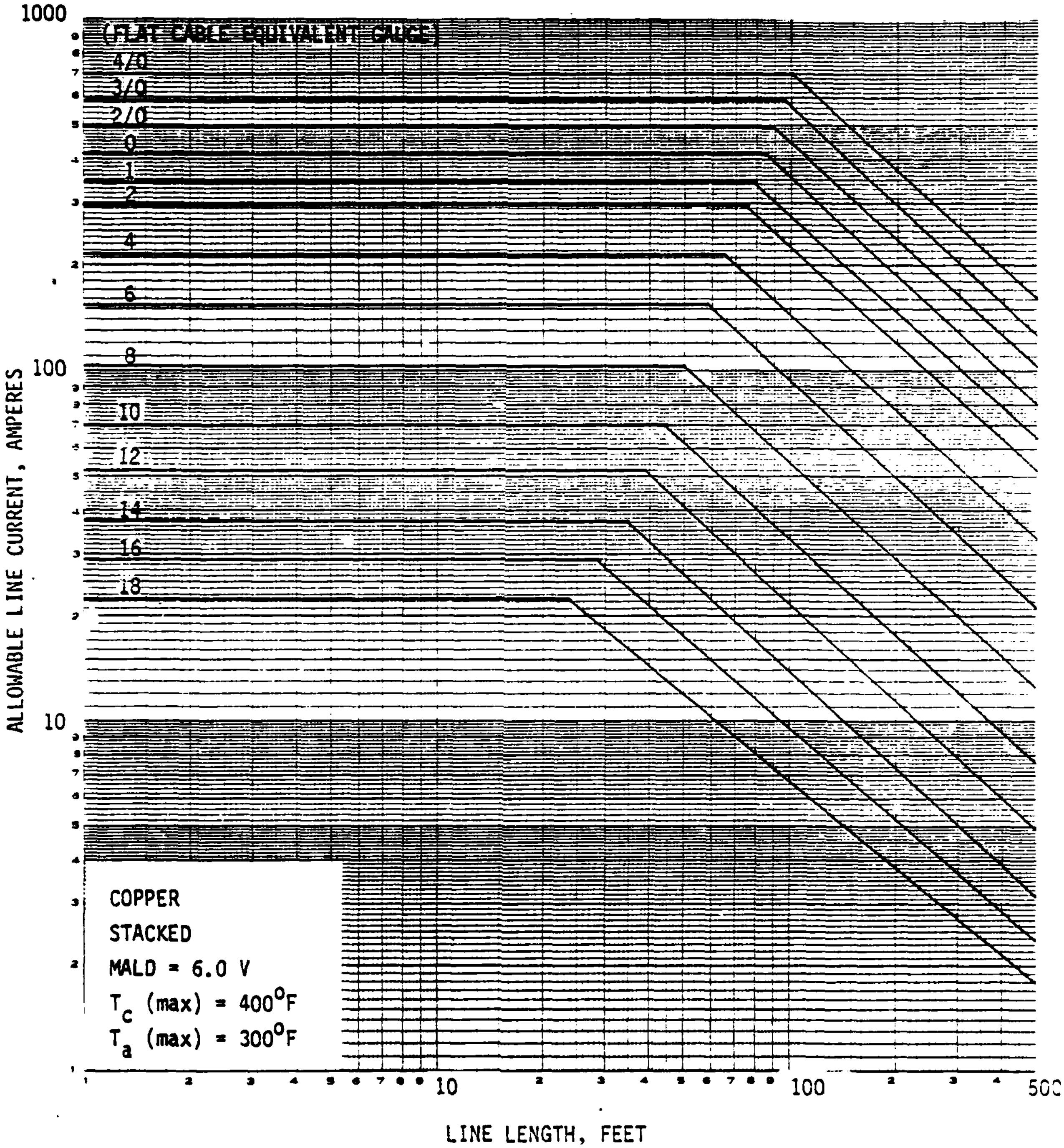

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.15
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



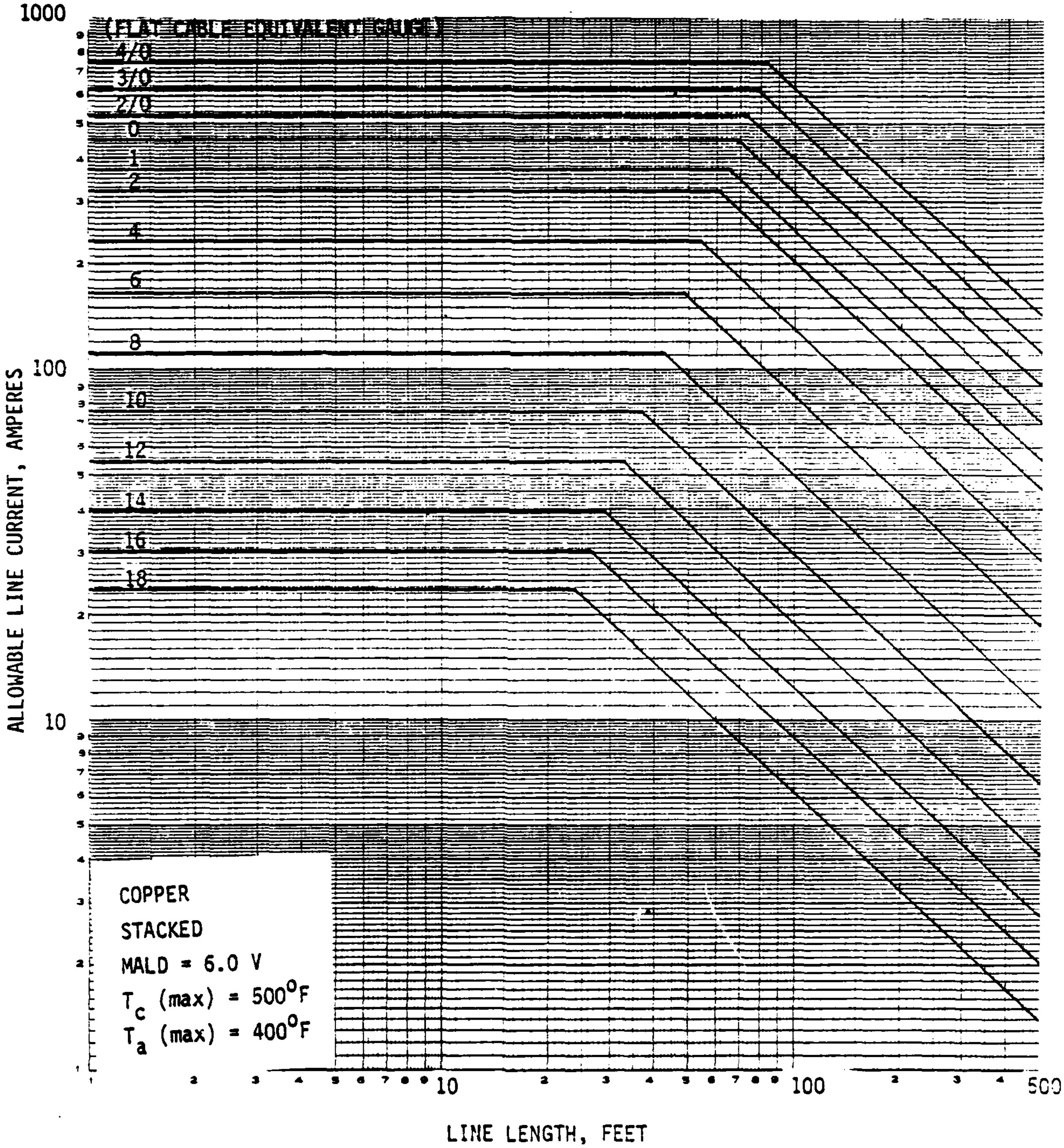

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.16
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



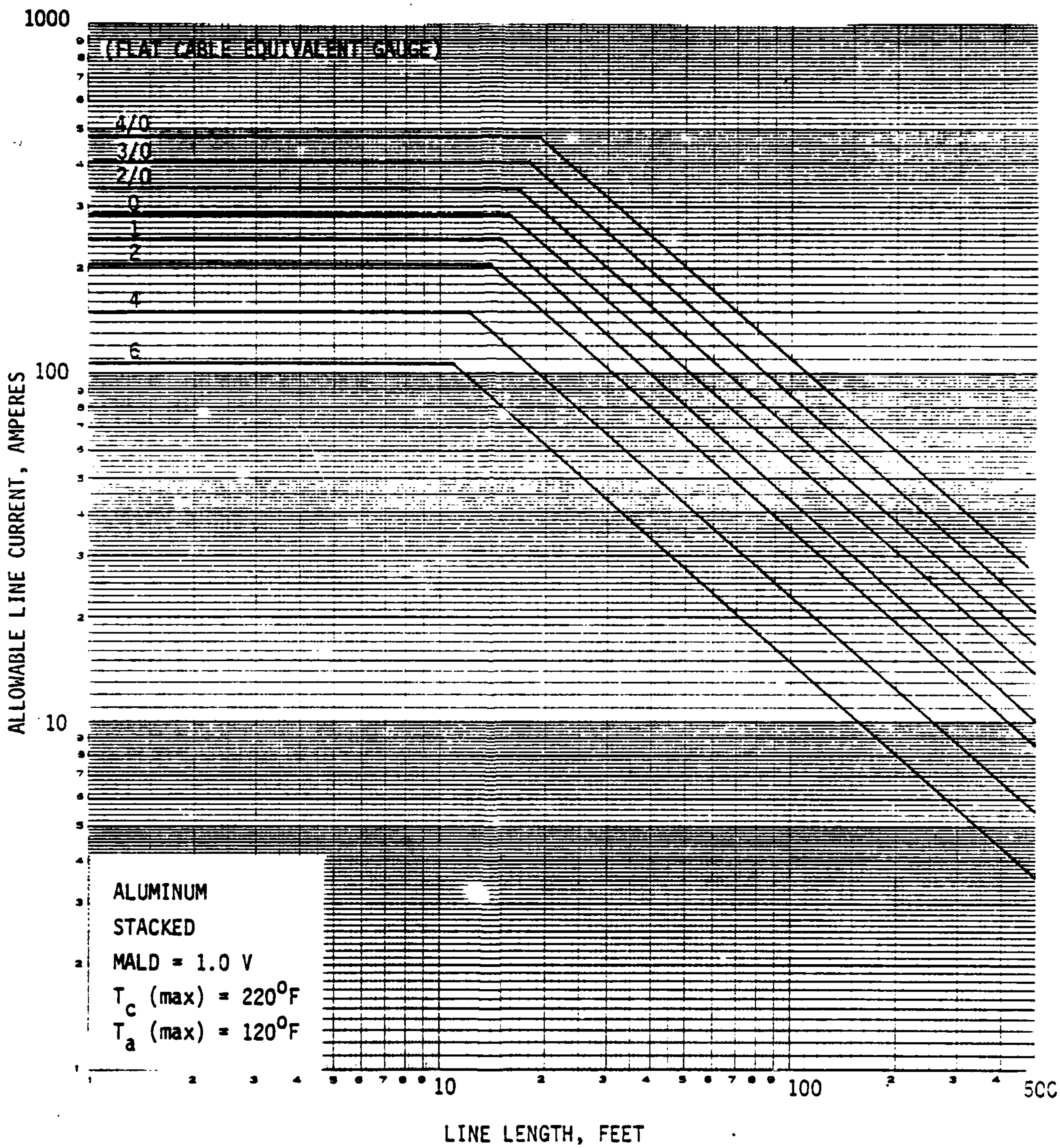

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.17
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



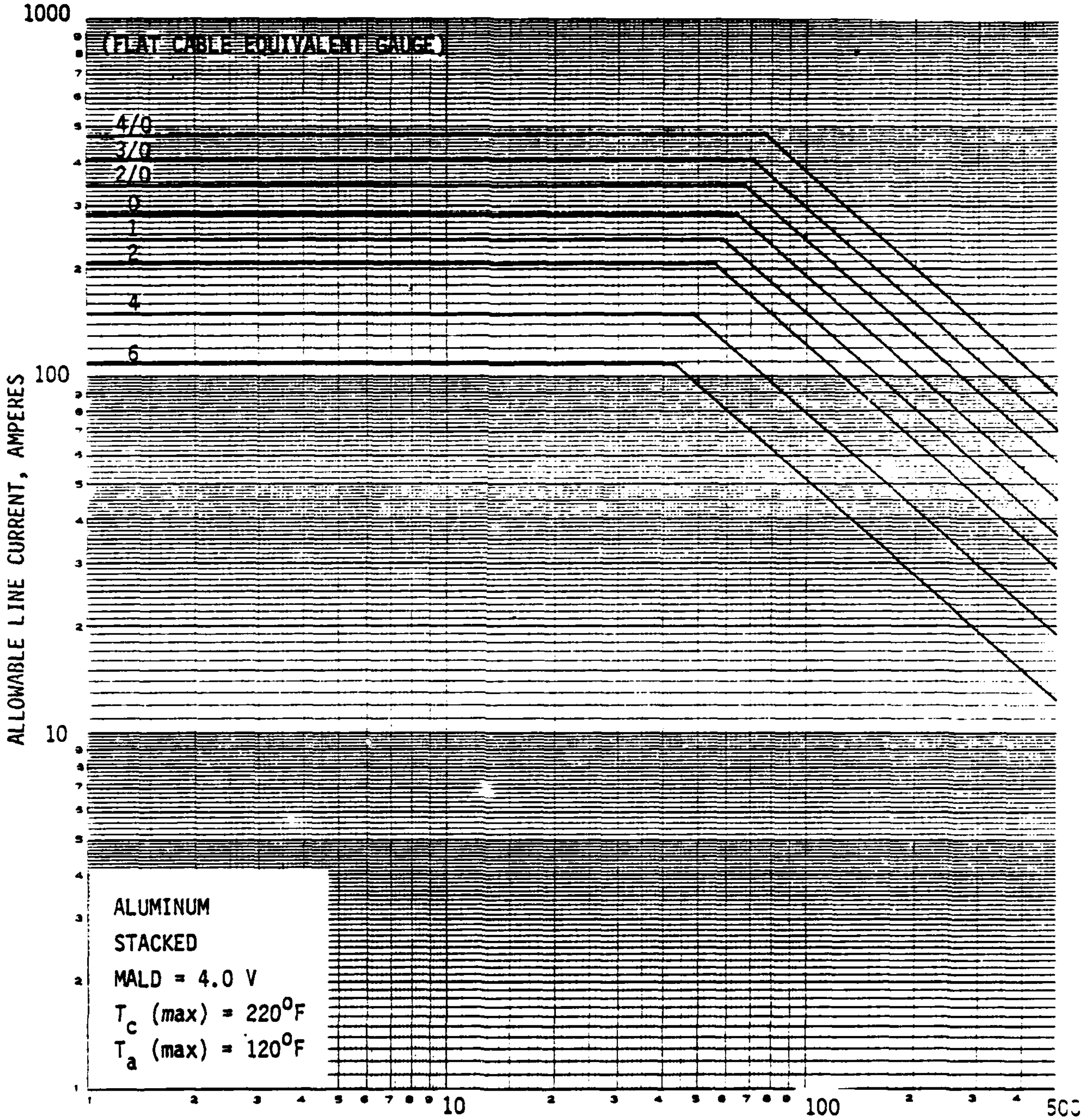

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.18
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



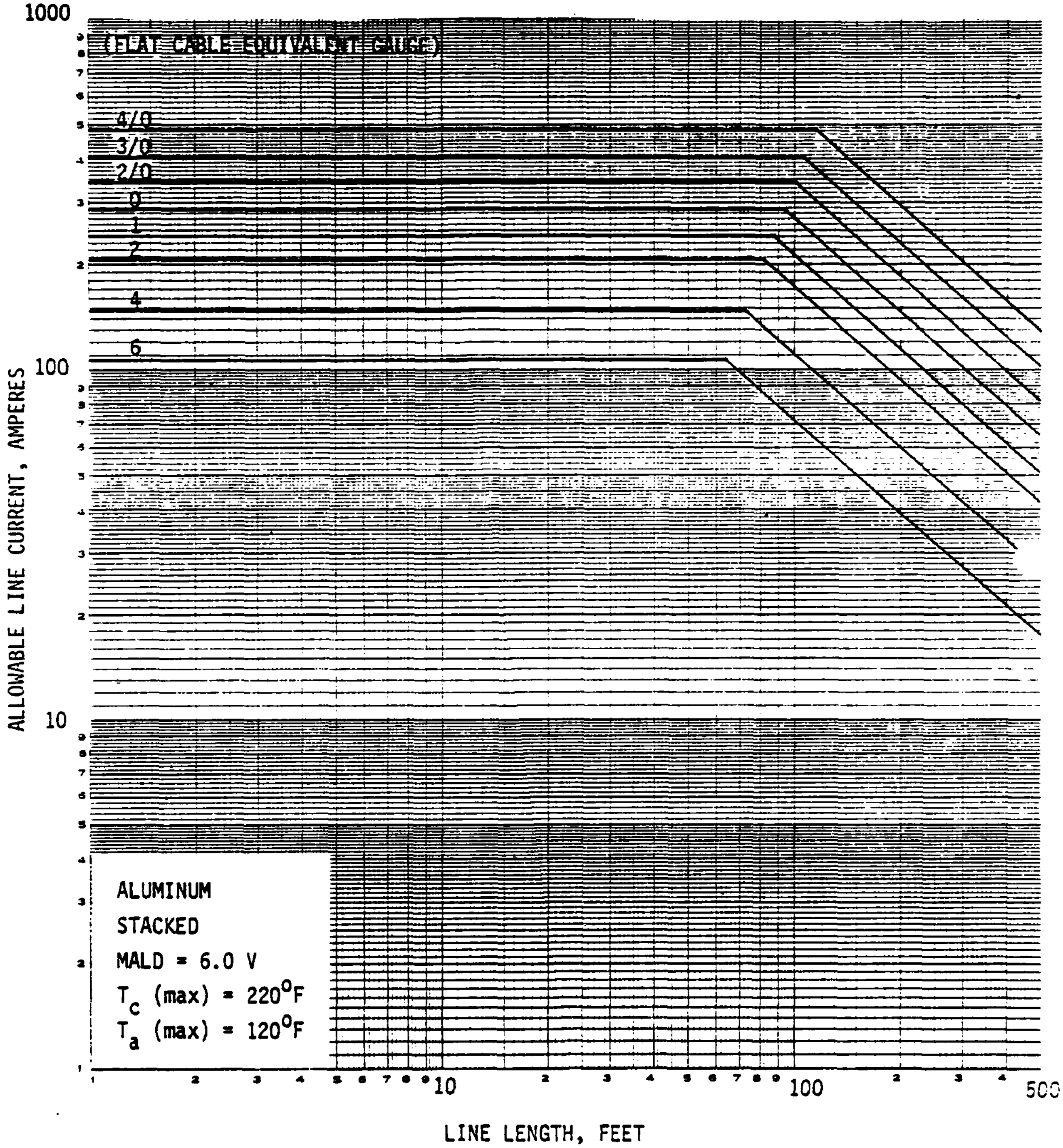

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.19
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



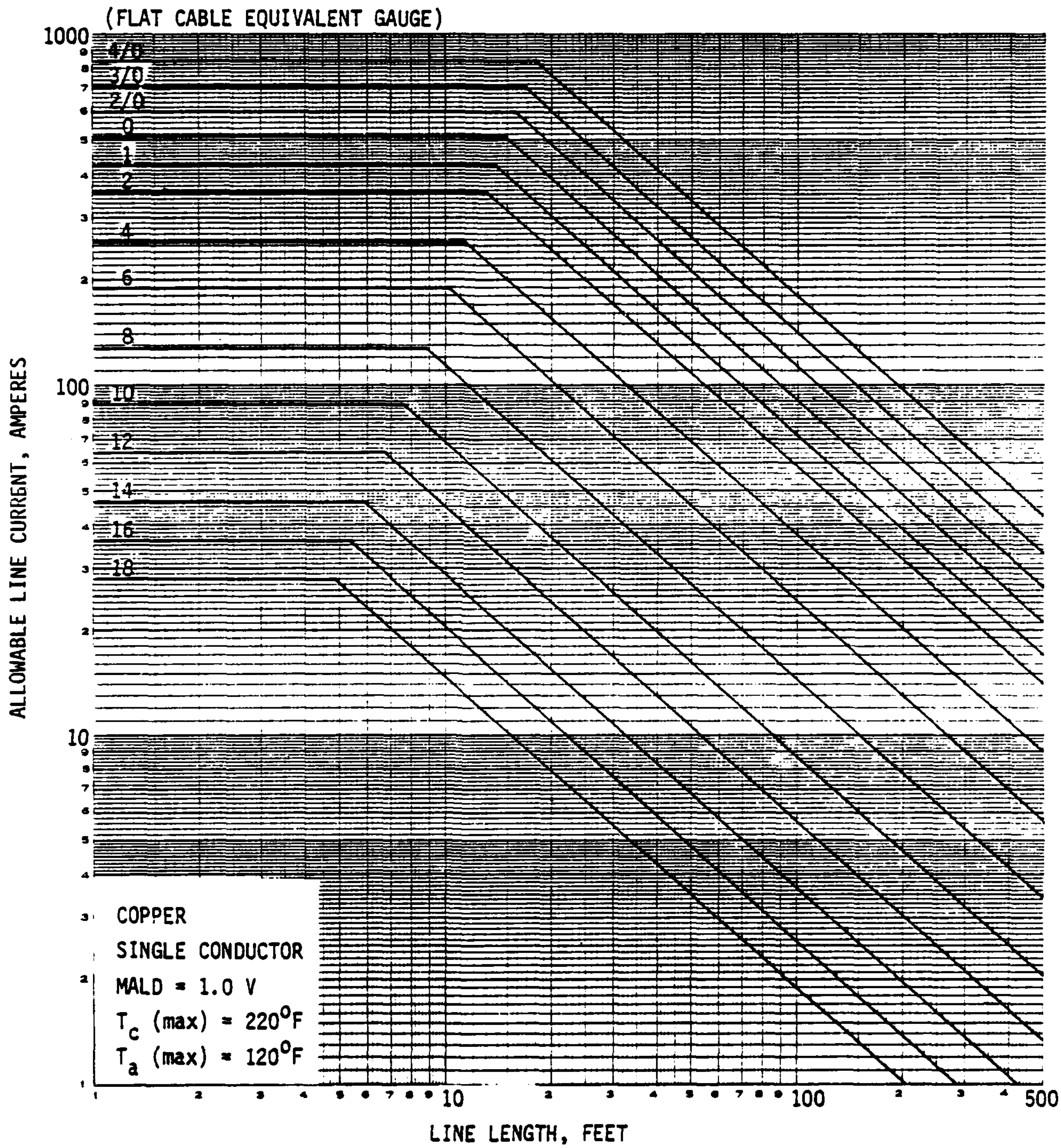

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.20
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



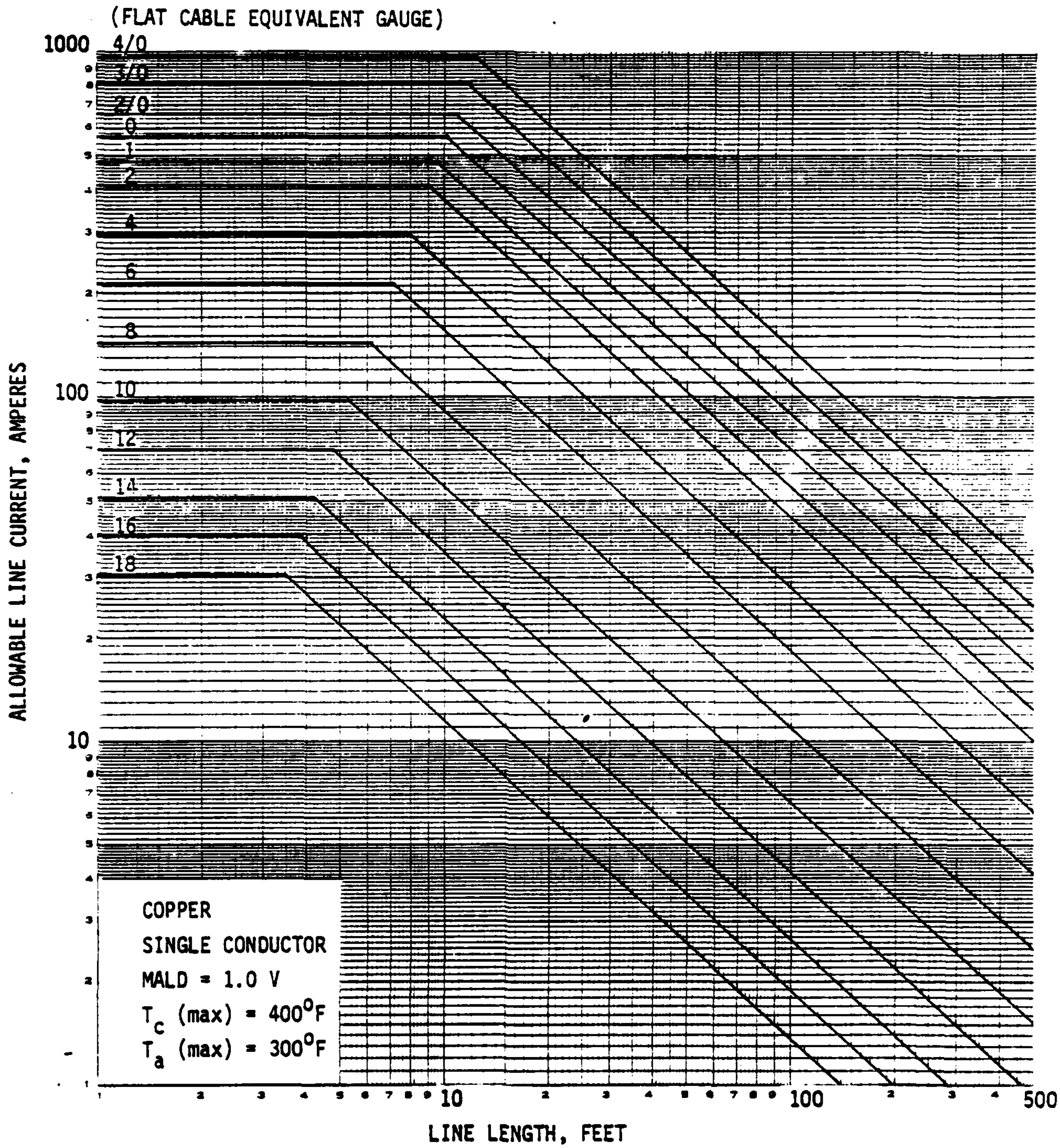

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.21
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



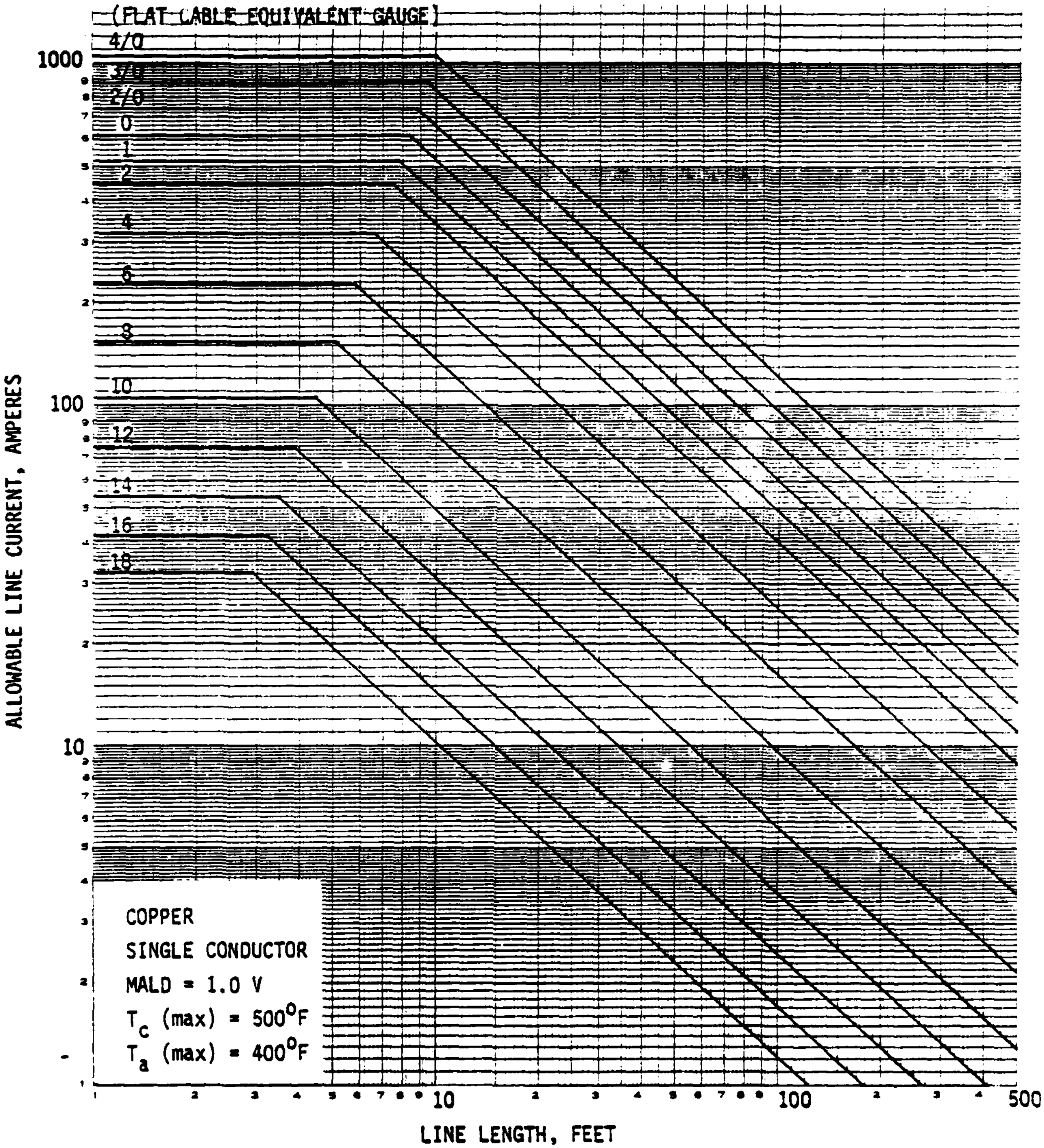

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.22
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



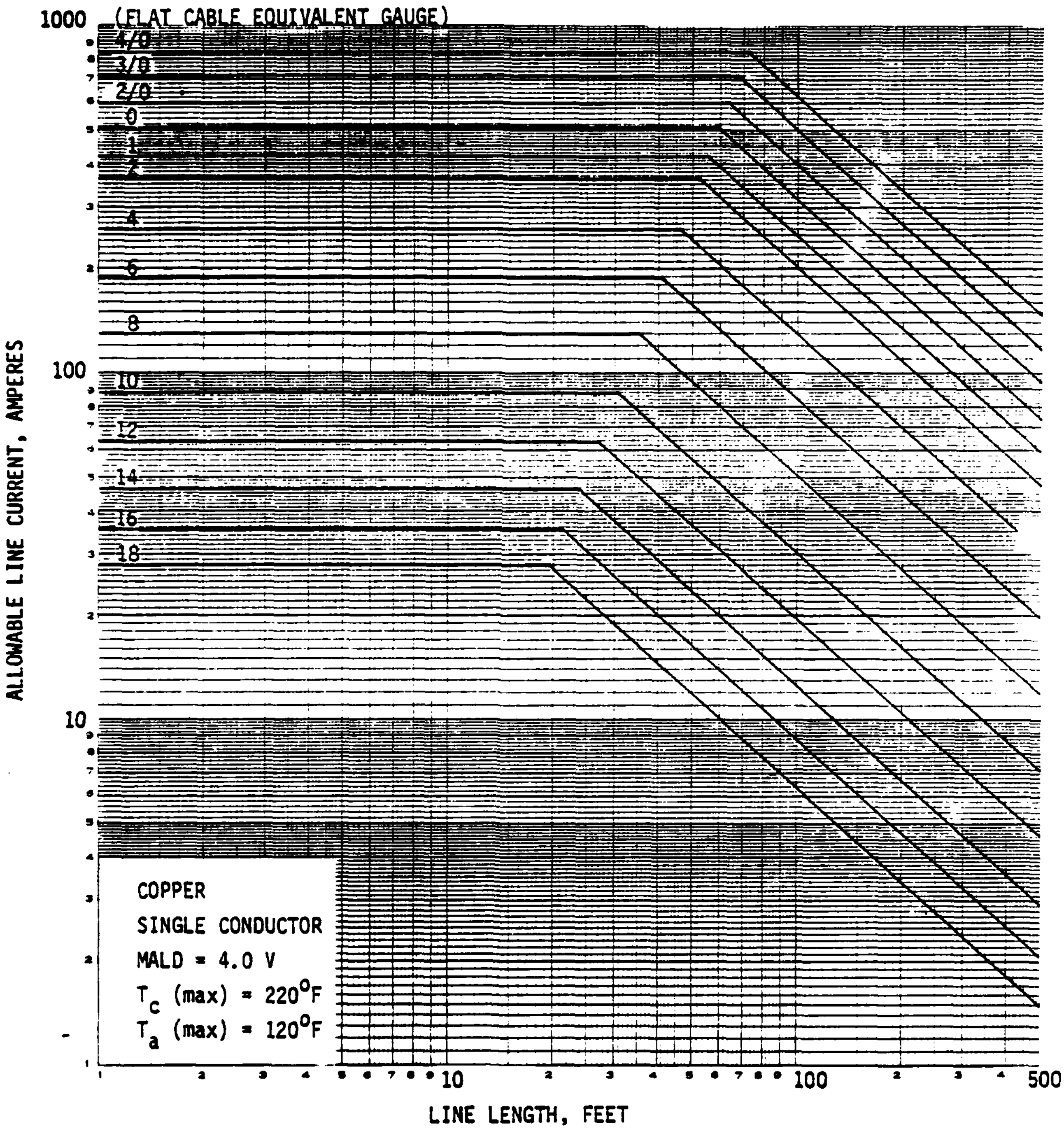

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.23
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



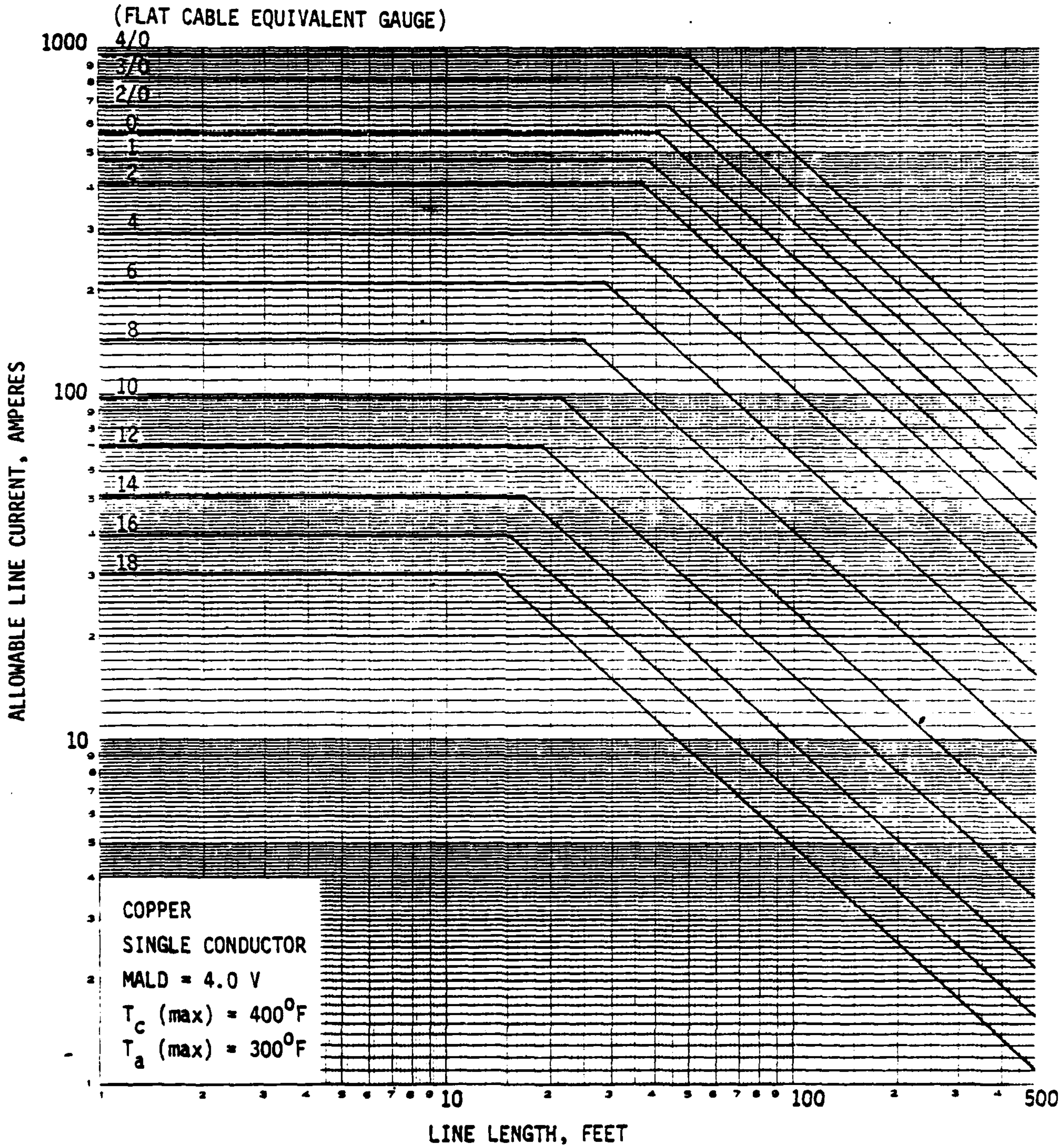

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.24
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



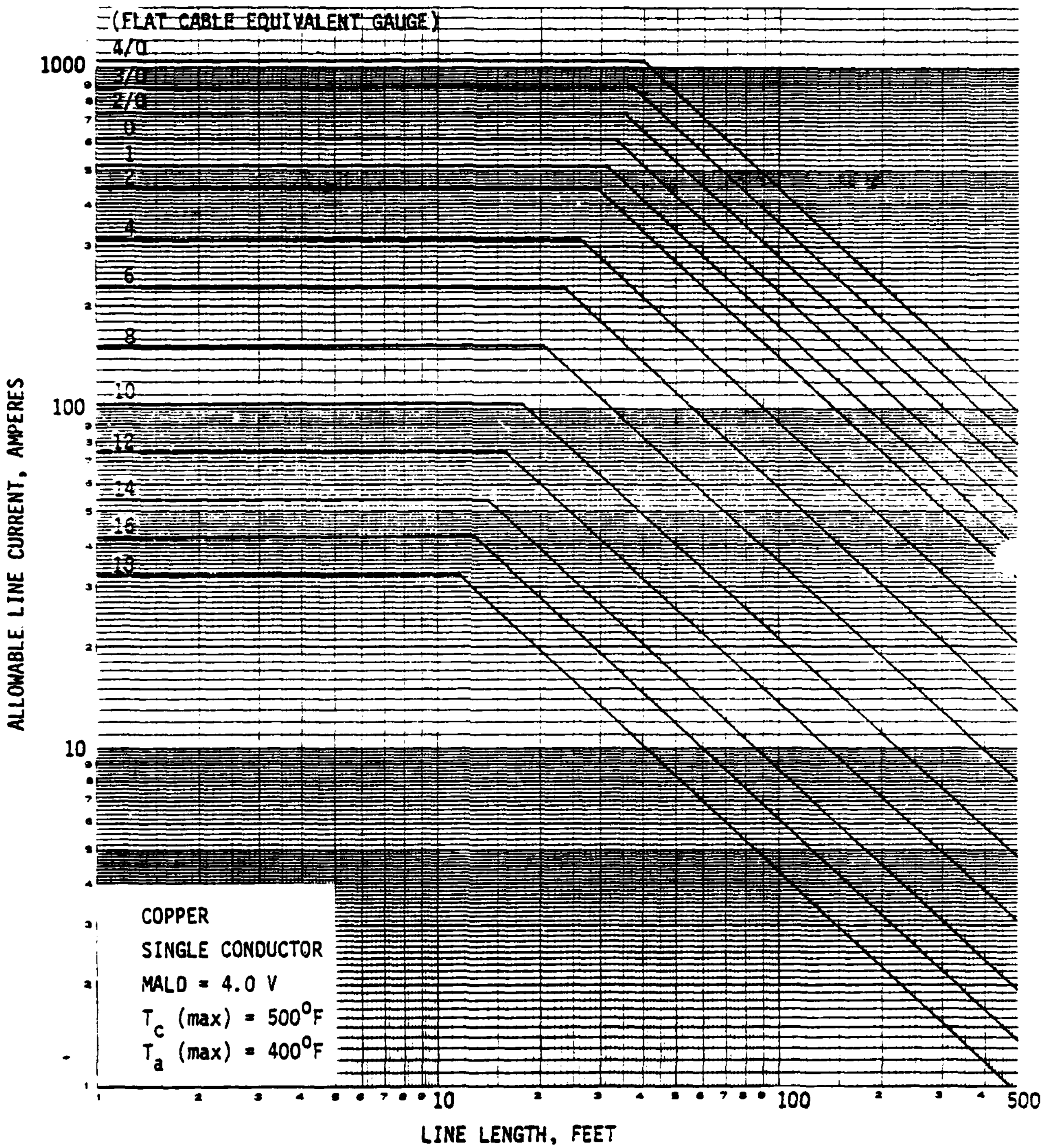

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.25
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



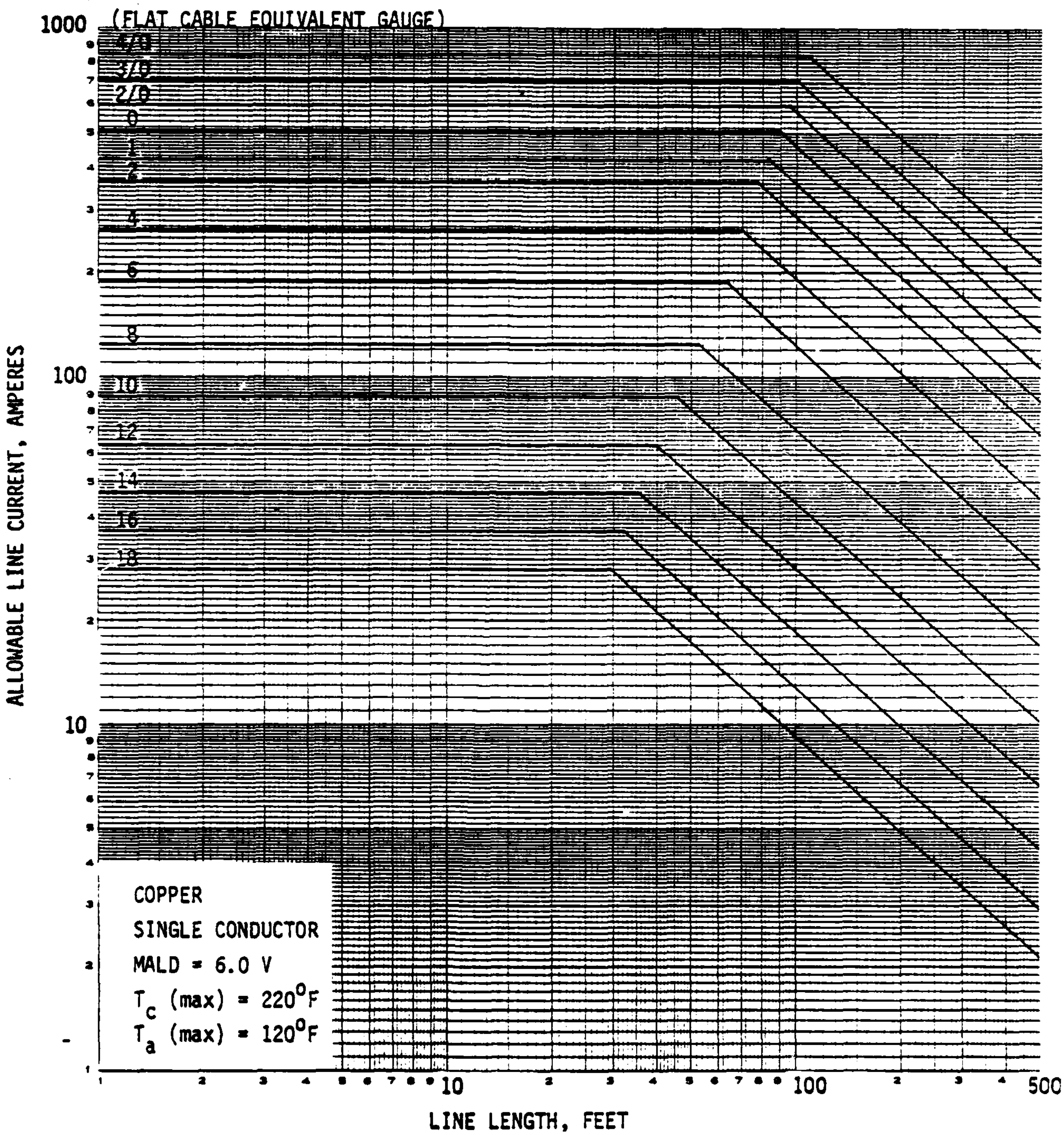

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.26
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



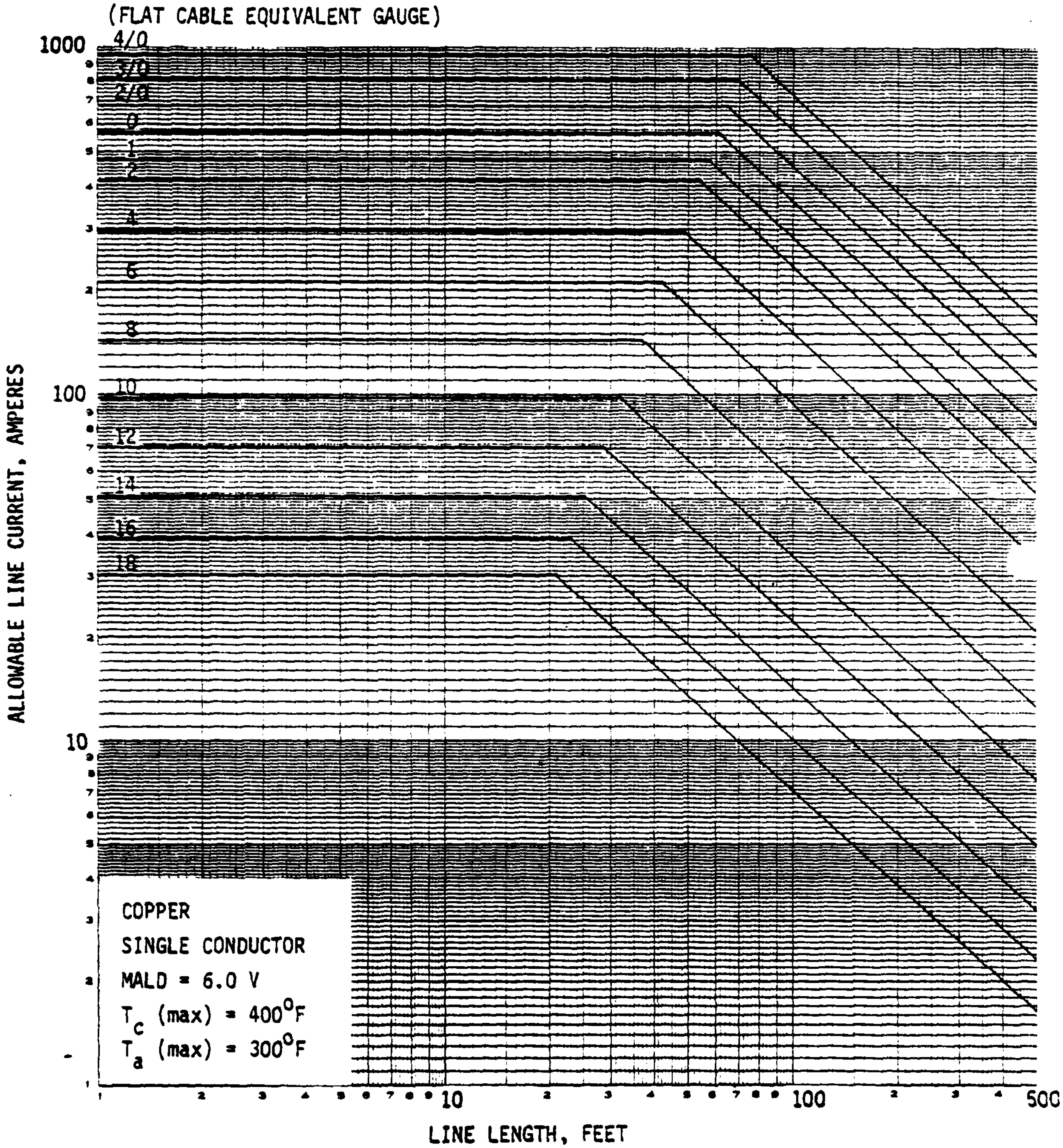

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.27
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



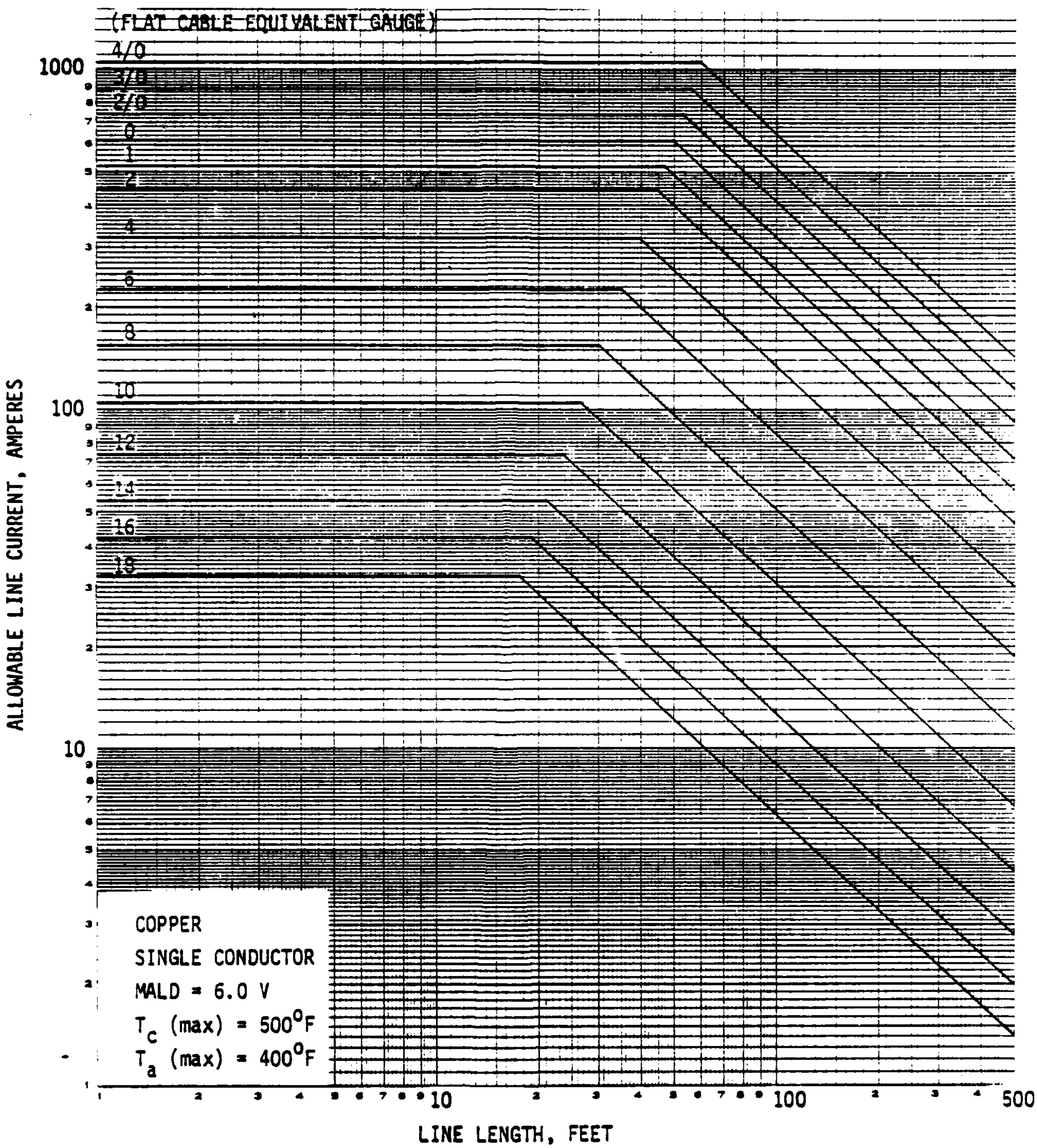

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.28
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



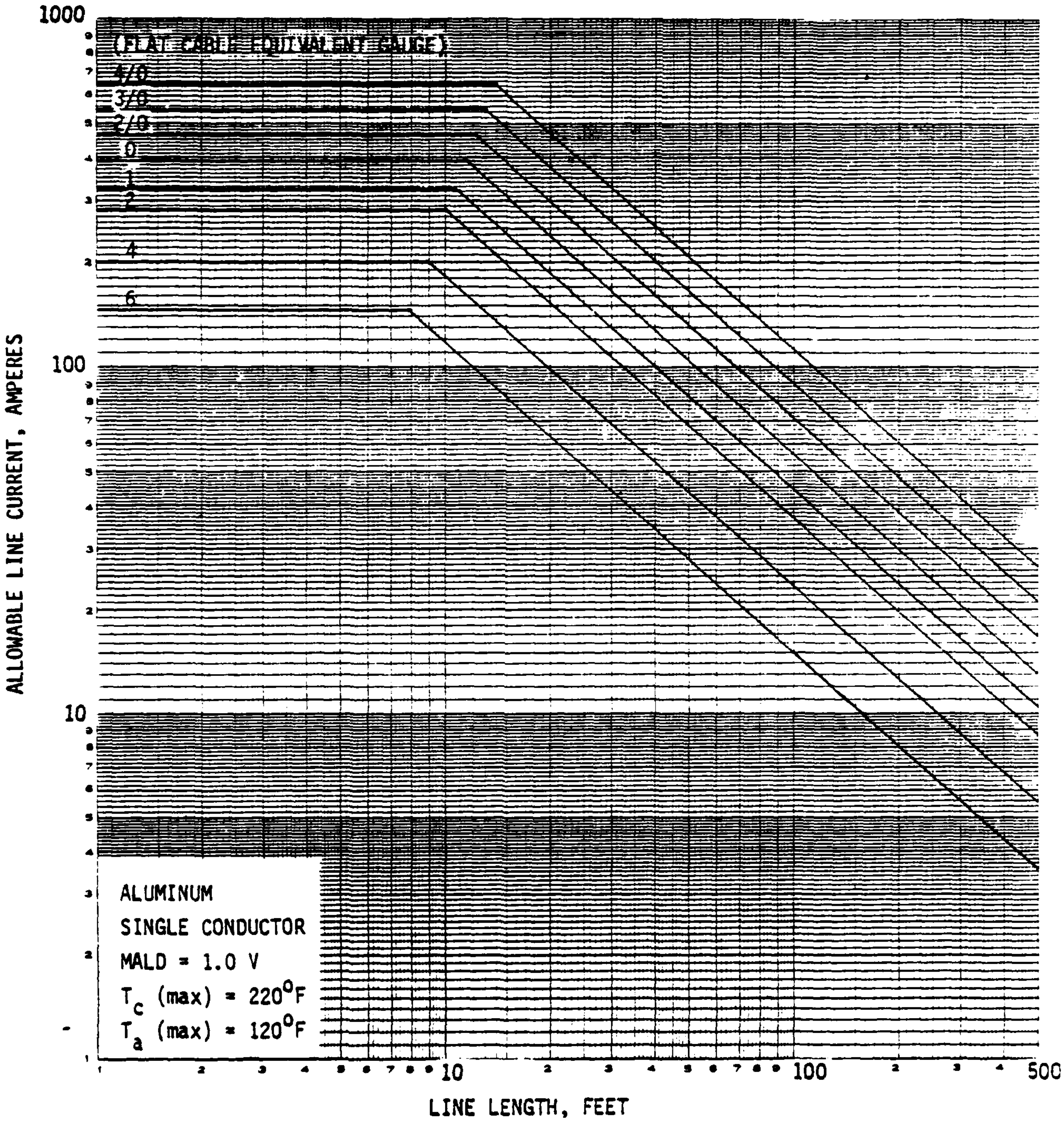

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.29
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



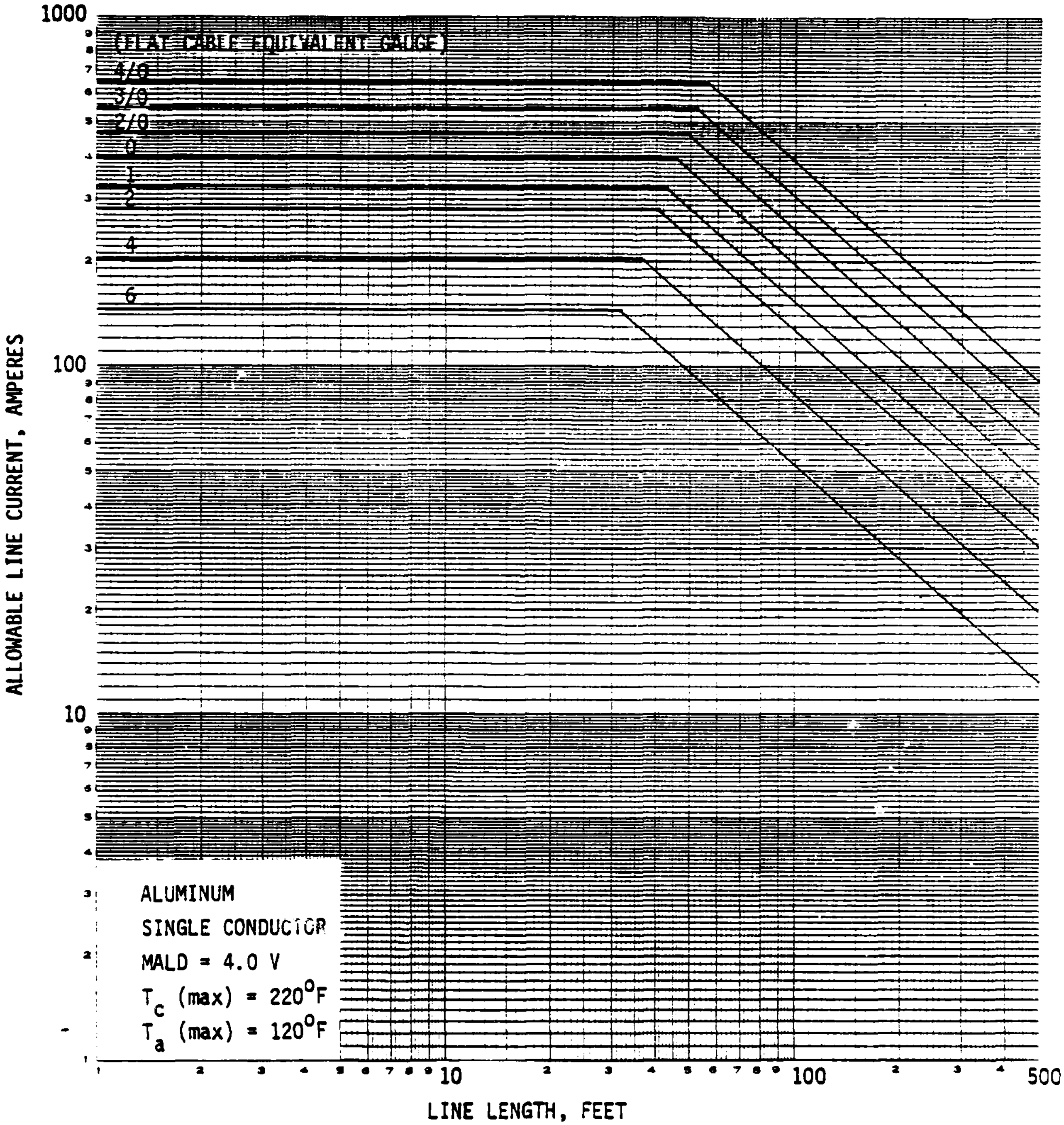

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.30
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP



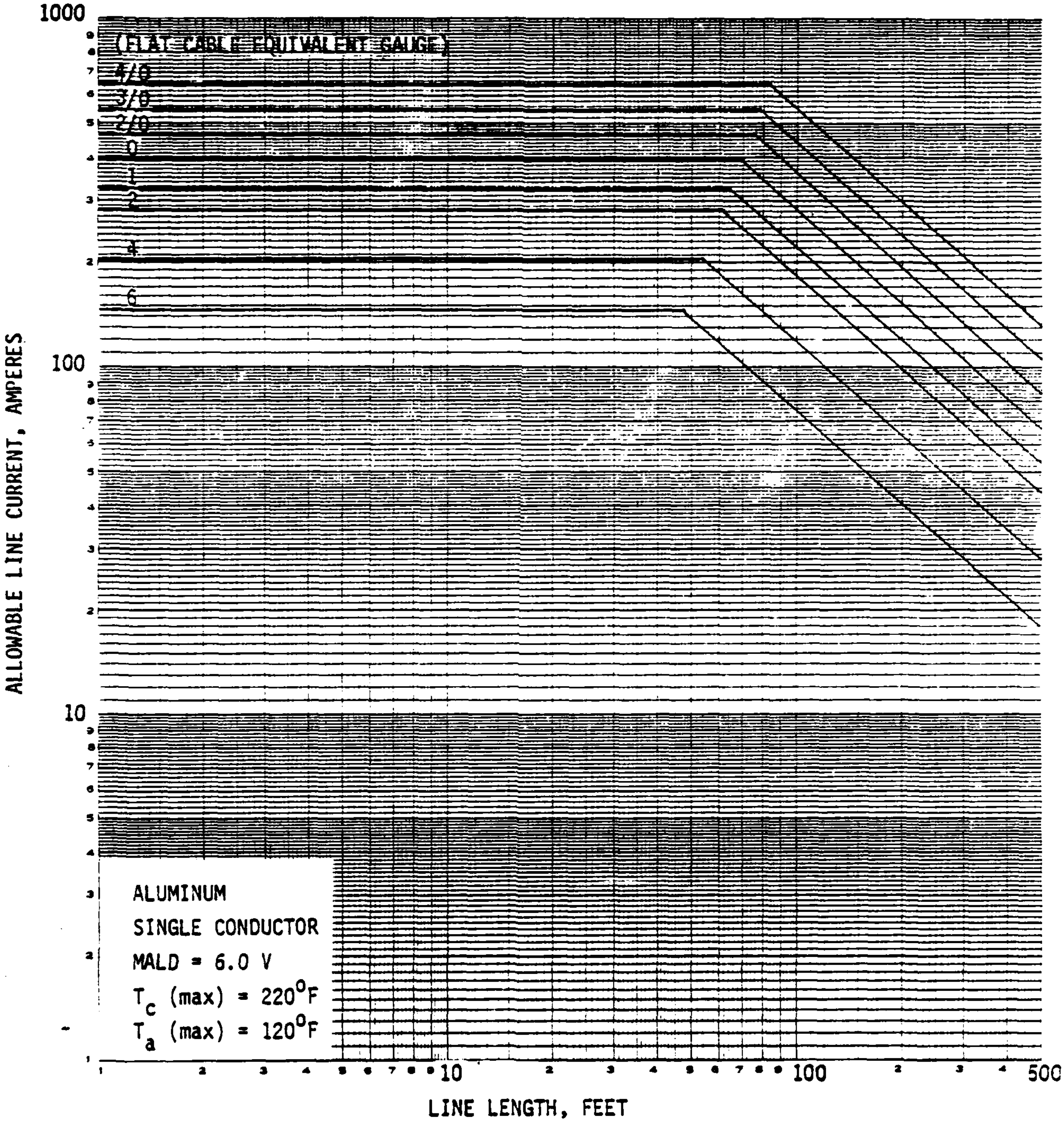

Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.31
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP




Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

FIGURE 4.5.32
LINE LENGTH VS. LINE CURRENT
VS. CONDUCTOR SIZE AT CONSTANT VOLTAGE DROP




Note: These curves are based on calculations for general conditions and should be used for preliminary estimates only.

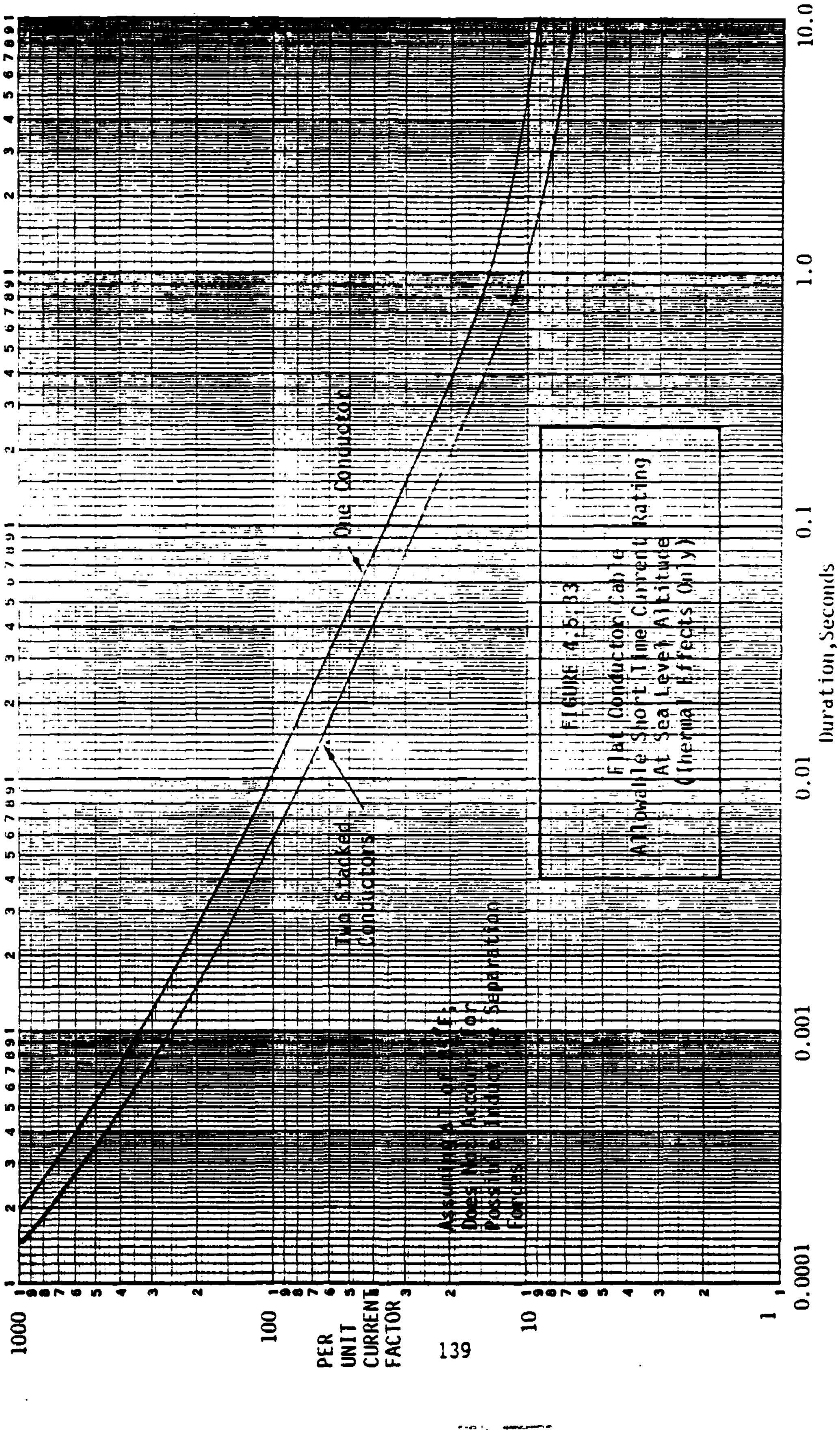



FIGURE 4.5.33
Flat Conductor Cable
Allowable Short Time Current Rating
At Sea Level Altitude
(Thermal Effects Only)

NOTE: This Curve Is For Preliminary Estimates Only

## 4.6 Flat Cable Electromagnetic Threat Considerations

This design guide does not provide information which will allow the designer to decide when and where to use shielding. If properly terminated, stacked flat conductors will require shielding in fewer instances than conventional twisted pairs. The requirements for noise reduction on aircraft electrical power distribution leads is dependent on a large number of factors which is beyond the scope of this guide to evaluate. What is provided here are feasible methods of shielding for flat cable when it is necessary. The circuit designer should use appropriate methods to evaluate the electromagnetic threat presented to a given circuit in a given installation and evaluate the selected methods of noise reduction to determine if tolerable noise levels are maintained. Special technical assistance can be obtained for analyzing threats and recommending solutions.

Section 4.6.1 gives a brief description of possible shielding methods and a discussion of the merits of each type. Section 4.6.2 outlines proper termination procedures for shielded and unshielded cables to ensure that the inherent "shielding" of flat cables is not lost to poor termination practices.

### 4.6.1 Flat Cable Shielding Methods

Conventional braided wire shielding (such as Federal Specification QQ-B-575) is definitely not recommended for flat cable due to a very high and unnecessary weight penalty.

The methods which are described below and illustrated in Figures 4.6.1 through 4.6.4 are considered reasonable within the constraints of performance, cost, weight, and producability. A discussion of the merits and risks of each method follows.

a. Faraday Box (See Figure 4.6.1) - A thin layer (3 mils) of metal foil (copper or aluminum) is used to line a raceway through which conductors are routed.

b. Strip Wrap (See Figure 4.6.2) - 2 or more strips of thin metal foil are woven around the conductor(s) in opposite rotations. Inclusion of small gauge drain wires at the conductor edges (beneath the foil) eliminate a solenoid effect of the wrapping.

c. Continuous laminate (See Figure 4.6.3) - Metal foil strips slightly wider than the conductors are laminated to both sides of the conductor(s). Drain wires at either edge are optional.

d. Shield/Sleeve Combination (See Figure 4.6.4) - A pre-constructed sleeve made of fine wire mesh or thin foil encased in plastic is placed tightly around the conductor(s). An optional zipper or similar fastener will allow sideways insertion/extraction.

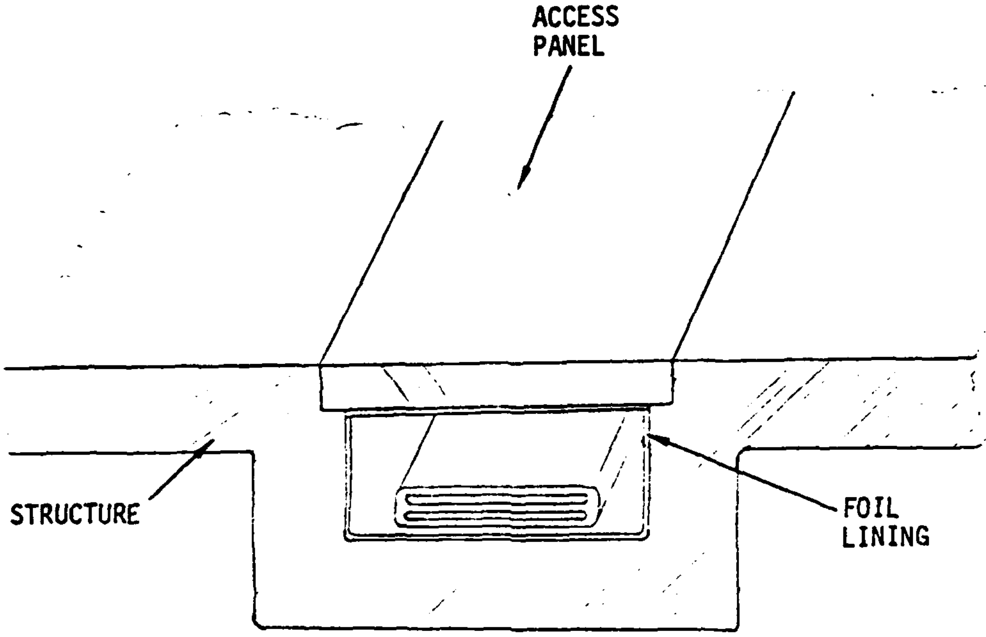



FIGURE 4.6.1

FLAT CABLE SHIELDING
BY FARADAY BOX

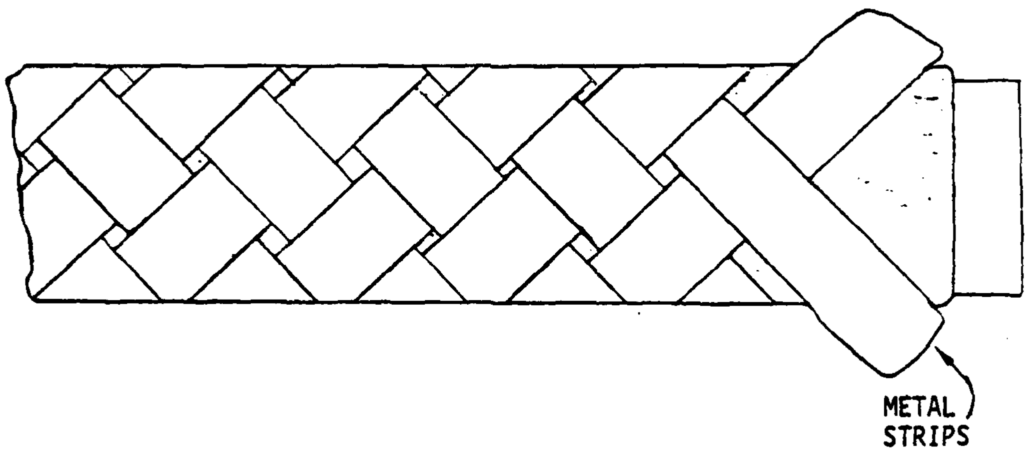



FIGURE 4.6.2

FLAT CABLE SHIELDING
BY STRIP WRAP

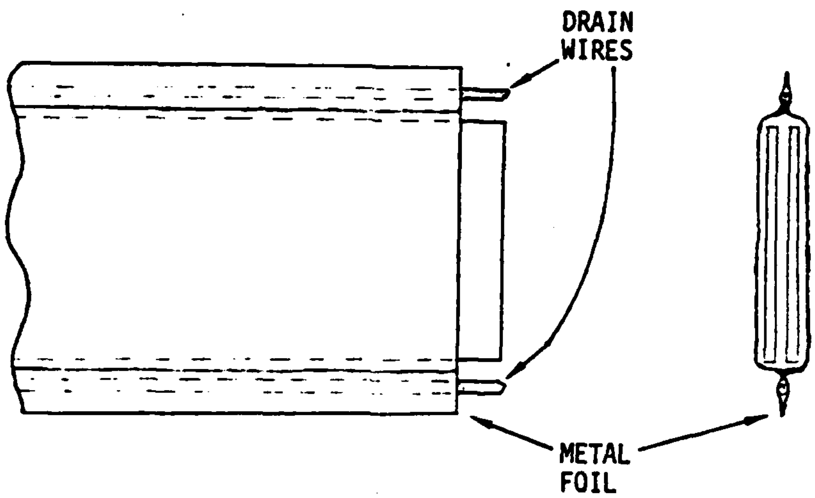



FIGURE 4.6.3

FLAT CABLE SHIELDING
BY CONTINUOUS LAMINATE

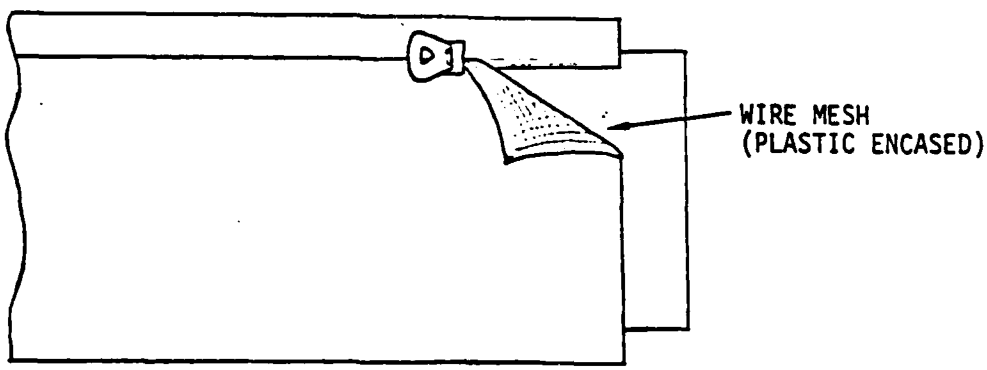



FIGURE 4.6.4

FLAT CABLE SHIELDING
BY SHIELD/SLEEVE COMBINATION

The advantages and disadvantages of the methods are as follows:

a. Faraday box - This is the most effective method given, as it greatly reduces secondary coupling between the shield and conductor. It is more difficult to manufacture than other methods and the weight is quite high unless the raceway is used for several conductors, thus distributing the added weight among several harnesses.

b. Strip Wrap - This method has moderate effectiveness and higher weight than the other methods given (except for the Faraday Box above), but it is simpler to manufacture and has greater flexibility than the other directly applied methods (the Faraday Box has no flexibility requirements).

c. Continuous Laminate - The effectiveness is second only to the Faraday Box. The weight is lowest of all methods and it is easy to manufacture (Second only to the Strip Wrap). It is the least flexible of all methods given, and may result in premature failure of the shield at folds in the harness.

d. Shield/Sleeve Combination - This method has moderate effectiveness and is very easy to incorporate during manufacture, although the initial purchase price is higher. The weight is relatively high due to the additional plastic encasement, but this encasement eliminates the need for additional abrasion sleeving. If a side access is incorporated, this feature facilitates manufacturing assembly and later maintenance operations.

4.6.2 Proper Termination Procedures

The most important aspect of terminating flat cable is to realize that incident electromagnetic fields must be restricted to the outer shielding and electrical equipment cases. By maintaining a continuous Gaussian surface around the equipment, the net magnetic flux inside the surface is zero and incident fields have no effect on internal components. Of course, a perfect Gaussian surface is not practical on military aircraft as this would require several inches of solid lead around components. However, observation of proper termination procedures for ground plane conductors and shields (when present) can approximate an ideal enclosure.

For unshielded stacked conductor pairs, it is critical that the conductors remain quite close together until well surrounded by the metal case of the source/load equipment (or the metal case of a connector backshell or terminal block). The ground plane should have a low inductance, low resistance connection from the ground plane, before the entry point into the case, to a point on the exterior of the case. Low inductance can be achieved by using a flat, braided wire mesh rather than a round wire pigtail.

In situations where this grounding scheme cannot be accomplished easily the following changes, in order of decreasing desirability, are possible:

a. A round wire pigtail can be used in place of the flat, braided ground strap.

b. The flat braid can be connected to the ground plane just inside the metal

case and routed back to the exterior of the case.

c. A round wire pigtail can be used in place of the flat braid in b.

d. A flat braid can be connected to the ground plane just inside the metal case and connected to the nearest available point on the interior of the case.

e. A round wire pigtail can be used in place of the flat braid in d.

Thus far, in the discussion of unshielded flat conductors, continuity of the surface has been maintained for the ground plane conductor, but not for the positive conductor. It is not possible to provide a DC continuity from the positive conductor to the equipment case, but there is a high frequency AC continuity via the large distributed capacitance of the conductors.

The cutoff frequency, i.e., the frequency below which stray signals are unaffected, is a function of the length of the run, the spacing of the conductors, and the dielectric material between the conductors. Should high power, low frequency signals be of concern, the use of inductive chokes, spark arrestors, metal oxide varistors, and/or avalanche (Zener) diodes may provide an attractive alternative to shielding to selectively enhance the apparent continuity of the external surface.

For proper termination of shielded flat conductors, the grounding scheme is similar but for one exception: continuity through the outer metal surfaces should be between the shield and metal cases. No effort should be made to

deliberately join the shield to the ground plane conductor except in low E.M. threat areas. If the circuit ground reference is in electrical contact with the interior of the metal case, this situation will not contribute significantly to circuit noise levels and is therefore acceptable.

At the end of a harness the shield must be electrically joined to the equipment case, connector, or terminal block. The shield should make a 360 circumferential connection at the case, connector backshell, or terminal block.

4.7 Routing Path Considerations for Flat Cable

The routing considerations for flat cable present a sharp break from traditional considerations for conventional round wire. Almost every method in current practice for round wire routing must be modified, with the elimination of some considerations and the addition of others.

Candidate paths should be evaluated for conflicts between the following factors. The factors are presented in an approximate order of decreasing importance. However, in the event of a conflict, the designer should use his own judgement in establishing which factor should have precedence.

4.7.1 Support and heat transfer. Take advantage of inherent cable support where possible by routing against bottom skin or structure, unless these surfaces are expected to be hotter than ambient temperature.

4.7.2 Avoid high electromagnetic threat areas. The lowest threat area is the

interior-most, tail section of the fuselage. The threat increases towards the nose, leading edge and upper surfaces of the aircraft.

4.7.3 Avoid areas where personnel, equipment, or payload traffic is expected. Do not route the cable where it can be easily used as a hand hold, stepped on, chaffed or abused.

4.7.4 Avoid areas that may contribute to chemical degradation, such as near electrical storage batteries, equipment, or lines containing hydraulic fluid, cooling systems utilizing ethylene glycol, etc.

4.7.5 Eliminate unnecessary course deviations that require sharp twists and turns. As a way of evaluating the routing of a candidate path, the following routing factors provide a method of numerically estimating the complexity of a path. Note these factors are engineering estimates for this initial design guide and require refining and updating as experience with flat cable is acquired. The numbers given are composite figures representing the difficulty of installation and the harshness of twisting and bending that the cable will experience while in service. It is desireable to reduce the sum of routing factors to a minimum.

4.7.5.1 Direct turn. The cable is folded along its width to the angle required. The allowable bend radius is a function of the size of the cable, the insulation used, and the presence of shielding/sleeving. The routing factor would range from 5 to 10, depending on the severity of the bend and the angle of the turn.

4.7.5.2 Parade turn. The cable is folded over on its self so that the plane of orientation remains the same. The sharpness of the fold is a function of the same factors as those of the bend radius in 7.5.1 above. The lay factor would be from 9 to 15.

4.7.5.3 Twisting. The cable is twisted about its longitudinal axis to allow for very slight deviations in course or to prevent buffeting due to high air velocity over the cable. Maximum twists per unit length are a function of cable size and insulation material. The lay factor would be from 2 to 6.

Where the cable must pass through areas of high vibration or places where chafing, buffeting, or abrasion are expected, abrasion sleeving should be used. Buffeting can be reduced by twisting the cable.

Two types of abrasion sleeve are in current use, both of which are a light-weight, braided, expandable tubing. The first type (type I) is made of polyethylene terepthallate which has a temperature range from $-65^{O}F$ to +250 F. The second type (type II) is made of ethylene chlorotrifluroethylene and has a temperature range from $-100^{O}F$ to $+300^{O}F$. The following table gives information for size selection and weight parameters.

TABLE 4.7.1

Design Parameters for Flat Cable

Abrasion Sleeving

| Type | Inside Diameter (Nominal) Inches | Braid Angle $\pm 3^0$ | Will Accomodate Flat Cable Sizes (AWG Equivalent) | Weight, Pounds per Thousand Feet (Max.) |
|---|---|---|---|---|
| I | .25 | 30 | 20,18,16 | 2.57 |
| II | | | | 3.96 |
| I | .50 | 30 | 18,16,14,12,10 | 7.81 |
| II | | | | 11.77 |
| I | .75 | 30 | 12,10,8,6 | 11.77 |
| II | | | | 18.19 |
| I | 1.25 | 37 | 8,6,4 | 16.05 |
| II | | | | 25.68 |
| I | 1.75 | 37 | 4,2,1,0 | 27.82 |
| II | | | | 40.66 |
| I | 2.0 | 37 | 2,1,0,2/0,3/0,4/0 | 35.31 |
| II | | | | 51.36 |

Note that this sleeving adds less than 1% to the harness weight and cost. Some manner of fixing the sleeve at its ends is required, such as a heat shrinkable boot or a clamp.

For paths where the length may vary in service due to airframe thermal expansion/contraction or flexing, a method of providing for this change in length is required. Some possibilities of accomplishing this task are illustrated in Figure 3.5.6.1.

The advantages and disadvantages of the four methods shown are given below:

'U' Bend

Merits: Lowest profile

Risks: Larger surface required, possibility of work hardening at the folds

Accordion

Merits: Lowest total space penalty

Risks: Excess can "flop around" and become damaged

'S' Bend

Merits: Easiest to construct

Risks: Excess can "flop around" and become damaged

Spring Loaded Roller

Merits: Cable remains moderately taut

Risks: Cost and weight penalty of extra device

Out of these possibilities, the accordion configuration is considered the best overall performer.

Similar to the requirements for providing slack are the requirements to provide extra lengths at the cable ends for retermination. The custom for round wire has been to allow sufficient length for 3 reterminations. This number should also serve well for flat cable and can be accomplished with the forms given for providing slack or by the use of a drip bend.

4.8 Connections to Flat Cable

Connections to flat cable are categorized by the frequency of mating/unmating cycles. Less than 5 cycles/1000 flight hours is considered low; 5 or more cycles/1000 flight hours is high.

For low cycling frequency terminations, a semi-permanent connection is recommended, such as a terminal stud-and-nut lockdown plate. These are most frequently encountered at the generator(s), power distribution centers and sometimes at the utilizing equipment terminals.

For high cycling frequency terminations, a quick disconnect pin-and-socket type connector is recommended. The attachment of cable to connector contact can be accomplished by a variety of means, e.g., welding, soldering, bolting together or crimping. The last two methods, bolting and crimping, are considered preferable because they allow reterminations in the field aboard a fueled aircraft. Crimping is considered superior to bolting for weight and reliability considerations. Also crimping can be accomplished on a stripped

or unstripped conductor, while bolted on connections must be made to a stripped conductor.

In designing a flat cable termination several factors must be considered.

4.8.1 Terminations to flat cable are most sensitive to thermal cycling and vibration. The width of flat power cables dictates that the contact material have a coefficient of thermal expansion which is closely matched to the conductor material. Vibration may loosen the contact faces or tear the thin conductor away at the contact edge. Potting or a resilient backshell clamp is recommended for strain relief.

4.8.2 Circumferential grounding ($360^{0}$) of the shield (if present) is far superior to pigtail grounding before the terminal. By clamping the shield all the way around a terminal, ensuring shield continuity through the connector mating halves and pigtailing the connector body to shield ground, shield efficiency is maintained.

4.8.3 By designing connectors with insert arrangements and coupling features which are intermateable with current round wire connectors, problems with transitioning to round wire are eliminated.

A conceptual connector is shown in Figure 4.8.1

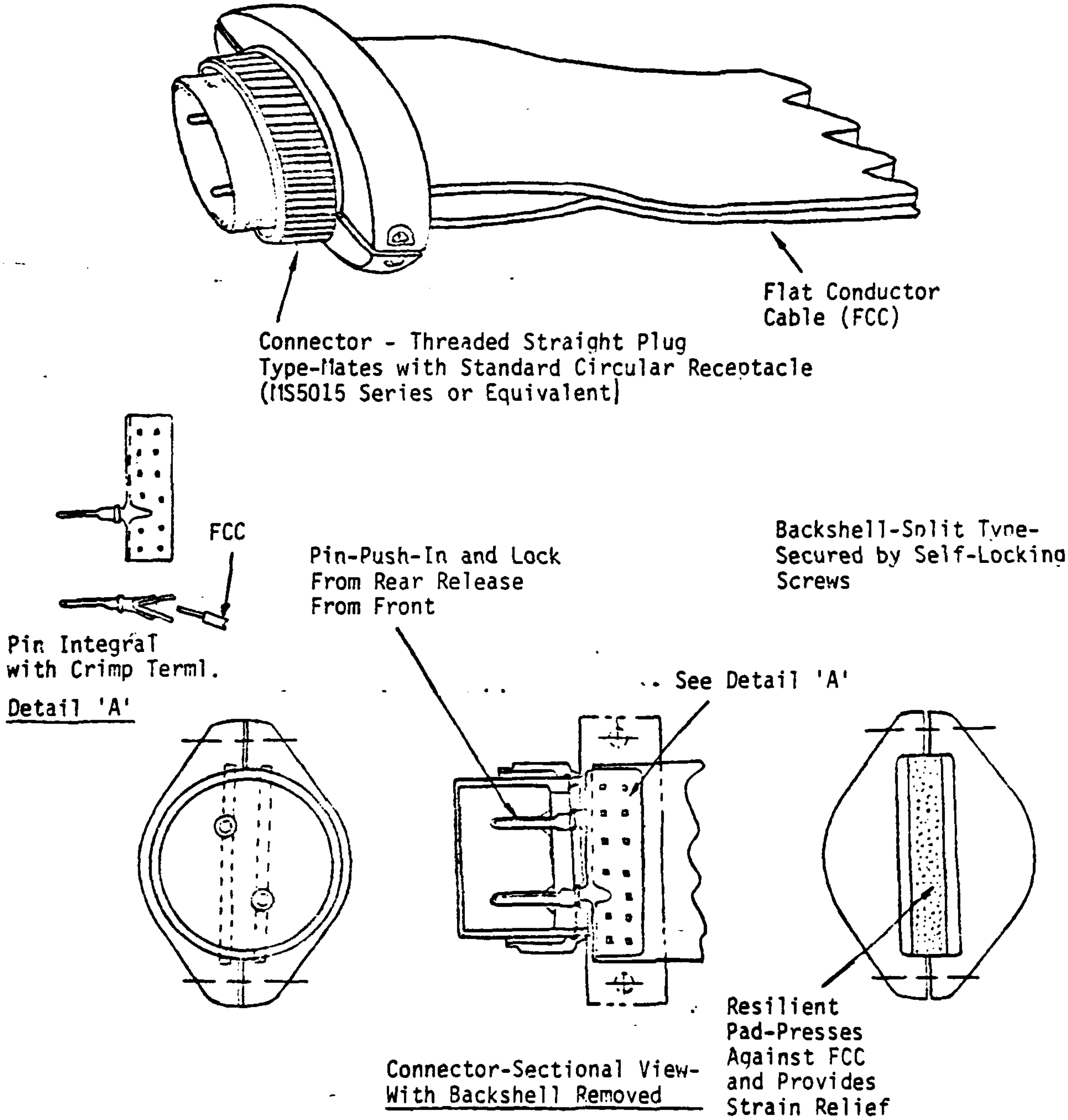



FIGURE 4.8.1

CONCEPTUAL DESIGN-
ONE-PIECE FCC TRANSITION
CONNECTOR

## 4.9 Harness Buildup and Installation Methods

As with round wire power feeders, flat cable primary and secondary distribution leads should not be routed in bundles with other wires, due to heat transfer and magnetic coupling problems. For round wire, some subsystem leads of low power (1-10 amps) are included in bundled harnesses with other wiring. Since flat cable is not recommended for usage below 10 amps, there should be no instances where flat cable is included in a bundle.

To form a flat cable into the final, installed product, a combination of preforming before installation and bending during installation must be used. The percentage of shaping done during installation will vary from harness to harness. Depending on the complexity of a given harness, some bends or twists might be postponed until installation to facilitate packing, shipping, handling and feedthrough. It is recommended that a designer optimize the extent of harness preforming by selection of feed-through starting points and utilizing inherent splices (such as copper to aluminum). The use of splices to avoid an installation routing difficulty is not recommended, as these splices reduce system performance and reliability. The buildup of the harness should follow the sequence given below:

4.9.1 Cut the conductor(s) to the required length and bond together (if bonding is necessary). Mark as required.

4.9.2 Install/apply shielding and/or sleeving to the cables if required. Terminate shield/sleeve as appropriate, i.e., temporarily taped down or permanently attached if no further interfacing will be required later.

4.9.3 Install and pot any pressure seal fixtures required.

4.9.4 Separate the conductors 6.0 inches from either end and strip insulation as required.

4.9.5 Lay out the cable on an appropriate form board and make any bends or folds possible prior to installation. Put a slight crease or mark with a semi-permanent symbol where folds, bends or twists must be performed after installation.

4.9.6 Install quick disconnect connectors if required, or a temporary protective boot if termination will be made on the aircraft.

4.9.7 Test, pack and ship as required.

A typical harness assembly station is shown in Figure 4.9.1.

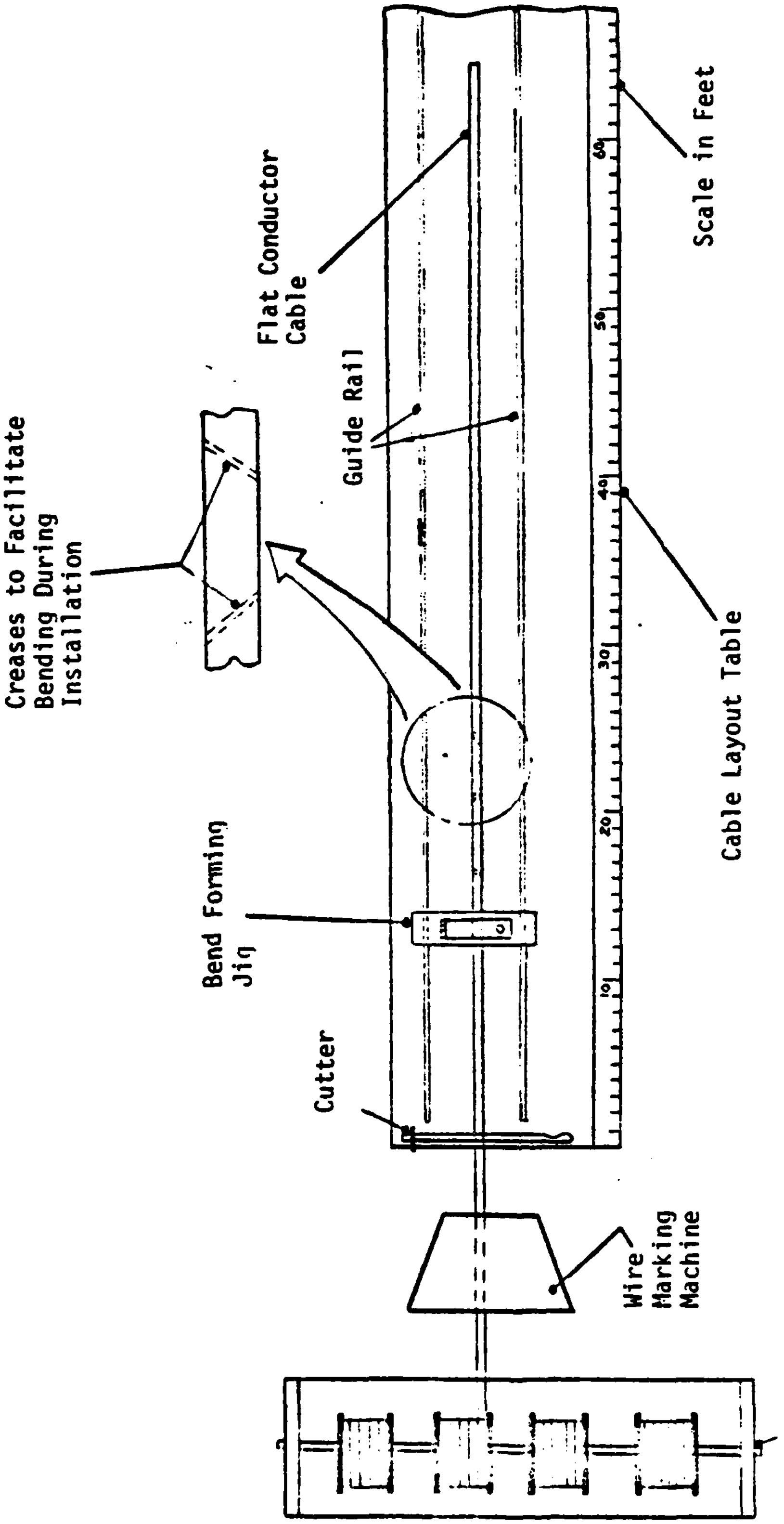



FIGURE 4.9.1

TYPICAL INITIAL HARNESS ASSEMBLY TABLE (PLAN VIEW)

## 5.0 FLAT CABLE ANCILLARY COMPONENTS FOR DEVELOPMENT

Flat cable components currently available are represented in the vendors proprietary information supplement to this report. No claim is made to the effect that this supplement represents every possible U.S. manufacturer of flat cable components. The information contained in the supplement is the result of a recent poll of aerospace quality wiring and connector manufacturers and distributors, and probably represents flat cable state-of-the-art technology.

As can be seen by reviewing this supplement, flat cable state-of-the-art technology is not yet up to the developmental level required for military aircraft. Many of the currently available components show considerable promise to achieve the appropriate result with a minimum of design, develop, test, and evaluate (DDTE) work, while other components virtually do not exist. The following list identifies and defines the flat cable harness components DDTE work to be done, in the order of priority required to achieve a satisfactory installation.

5.1 Flat Cable - Although the cable cannot be an ancillary component to itself, there are some developmental aspects with the cable that are critical to the development of the components.

5.1.1 Current carrying capacity and voltage drop verification. The graphs in the design guide for these parameters are based on computer calculations of steady state heat transfer phenomena. The mathematical modeling methods are at best accurate to within 10%, in light of the simplifying assumptions

required at this stage of flat cable development (i.e., insulation type and thickness, shield/sleeve type and porosity, cable construction and conductor separation, etc.). However, the mathematical modeling was performed with conservative parameters where possible. Hence, the experimental verification of flat cable current capacities and voltage drop parameters should show a slight increase over the values given in the design guide (i.e., higher current capacity at a given temperature rise and greater allowable lengths for a given current and voltage drop).

Sample lengths of flat cable should be obtained with various insulations (ETFE,FEP-PI, TFE) and then measurements made of the conductor temperature and voltage drop at various currents, ambient temperatures and pressures.

From these results, the current capacity and voltage drop graphs can be verified as is or adjusted as required. (Repeat same steps with aluminum and nickel plated copper conductors).

5.1.2 Selection of standard sizes. Once the current carrying capacity and voltage drops have been verified or adjusted, these results can be used to select flat conductor standard sizes with a width-to-thickness ratio of 150 of which the voltage drops most nearly match the voltage drops of conventional size round wires under identical conditions. It may be desireable to also add intermediate sizes of flat cables to allow finer divisions of the current carrying spectrum, which would further enhance the potential weight savings. The number of intermediate sizes added would be determined by optimizing the trade-offs between weight savings and several other factors:

a. The additional sizes will add to the costs of tooling and stocking with a similar impact on ancillary components.

b. Tolerances on the conductor dimensions would have to be decreased to prevent excessive overlap of the size. This decrease in tolerance results in an increase in manufacturing costs. A tolerance of -0.0%, +4.0% for thickness and -0.0%, +2.0% for width appears quite reasonable within the constraints of performance, uniform appearance, and manufacturing costs.

Although a precise determination of the number of intermediate sizes is beyond the scope of this study, an estimate would be 1, or at most 2 intermediate sizes between the flat cable sizes equivalent to conventional round wire AWG sizes on a voltage drop basis.

5.1.3 Cable manufacturability. Along with the conductor tolerances mentioned in the previous section, many manufacturing considerations for flat conductor cable will require investigation.

Types of insulation and methods of application are of major concern. Two methods in current practice for round wire insulation application are extrusion (ETFE and TFE insulations) and lamination (polyimide - FEP films). Extrusion is a simpler and less expensive method of application in the case of round wires, but this generalization may not hold true in the case of large (>#6 AWG) flat cables with a W/T of 150.

The width of the larger sizes of flat cable could not be accommodated by present extrusion equipment (according to W. B. Frogner, Hi-Temp Wires Co).

One possibility would be to curl the conductor, extrusion insulate the outer surface, uncurl the conductor, then either reverse the process to insulate the other surface for single conductors or laminate two conductors together with a thin dielectric film (Kapton R) between the uninsulated faces. (The suggestion for single sided insulation by curling is also by the courtesy of W. B. Frogner, Hi-Temp wires).

Rough estimates of the cost of the finished flat cable product range from 20% to 30% higher than the cost for equivalent sized round wires with similar insulation performance characteristics. It appears that existing equipment would be able to produce flat cable with nominal modifications to tooling and methods. The initial modification costs would be correspondingly low; hence, the increased cable costs would be due largely to a more complicated processing scheme for flat cable than with round wire.

5.1.4 Cable Mechanical Properties Determination

Once the standard sizes and manufacturing methods for flat cable have been partly developed, mechanical properties of the flat cables should be determined. Military standard (or appropriately modified) tests for parameters such as abrasion resistance, bending radius tolerance, flex life, thermal cycling and tensile strength should be performed on the flat cable. Necessary modifications to the cable manufacturing processes should be implemented as required (e.g., if moderate bending causes the insulation to

pull away from the conductor at the inside of a bend, methods of enhancing adhesion should be investigated). Other mechanical problems which require testing and evaluation may occur as the cable manufacturing processes develop.

5.2 Cable Shielding - Requirements and Methods

The requirements for shielding on either flat cable or round wire is highly dependent on many factors, such as what level of noise is tolerable on a given power line, the source of threat (EMI, EMP, EMC) and other methods of controlling noise threats (filters, surge arrestors, etc.). Rather than providing a designer with a lengthy and difficult-to-understand study of examples and "if then" situations, what is needed is empirical information on the type and character of noise or hazard produced on flat power cables by various threat sources. This information should possibly be supplemented by laboratory measurement of effectiveness of various proposed shielding methods for flat cable (Section 4.6).

With this information, a designer only needs to examine a circuit's requirements, estimate the hazard level and then determine from the information whether the induced signals would exceed tolerable noise levels if the flat cables are unshielded.

Laboratory EM threat simulation should include incident electromagnetic fields of varying frequency and angle of incidence on the final design flat cable, both single and two, stacked conductor configurations, at various heights above a ground plane, with varying current levels on assorted sizes.

## 5.3 Connections To Flat Cable

### 5.3.1 Terminal Blocks

The use of terminal blocks for flat cable transitioning to round wire connectors is not recommended , due to both weight and reliability penalties that occur. However, terminal blocks are recommended for interconnections to equipment where a low cycling frequency(less than 5 mate/unmate cycles per 1000 flight hours) occurs.

There would be very little development work with these simple devices. A conceptual design for a terminal block can be seen in Figure C.1. As long as the body material meets the usual requirements for high voltage airborne equipment (e.g., outgassing, dielectric strength, thermal expansion, etc.), there should be little work involved in the development of these blocks. One possible insulator candidate is diallyl phthallate (Mil-M-14, type sdg-f). This material has been a favored connector insulation material for 20 years, and should perform well in this application.

One drawback to diallyl phthallate is that it is a thermosetting material (non-injection moldable). Until fairly recently, injection moldable plastics were considered to be inadequate for airborne electrical insulators due to their relatively easy destruction( melting) at moderately elevated temperatures. New developments in commercially available thermoplastics have been challenging thermosets in airborne equipment insulators due to higher melt temperatures. The injection moldable thermoplastics have a distinct advantage over thermosets where manufacturing times are concerned, which

usually cuts costs and lead times considerably.

Some thermoplastic candidates are polyphenylene sulfide (Mil-P-46174), poly amide-imide (Mil-P-46179), and polyether imide (Ultem, made by General Electric Co.)

### 5.3.2 Connectors

A conceptual design for a one piece flat cable connector is given in section 4.8. Design variables are also discussed there. Some additional considerations not mentioned in section 4.8 are that the connector sizes should be standardized to conform to the flat cable standard sizes discussed in section 5.1.2.

The crimp terminal shown in figure 4.8.1, detail 'a', may be either an insulation piercing type or applied to a stripped conductor. Due to thermal confinement in the connector, any current path should have at least a 30% greater conductance per unit length than the lead-in flat cable. Since the insulation piercing contact will not have the surface contact area of the stripped conductor crimp terminal, the resulting increase in size may make the insulation piercing contact too heavy to compete with the stripped conductor contact.

The development of a firewall connector should be a straightforward matter, as the proposed connector design utilizes many parts from existing round wire firewall connectors(e.g., insert materials and connector shells).

5.3.3 Splices

Splices will require very little development, as Amp, Inc., Termi-Foil units appear to be adequate. The only development required would be the splice configuration required for the flat cable standard sizes. Amp, Inc., has already expressed an interest in pursuing this action, concurrent with the standard size and military/aerospace requirements inputs from appropriate organizations.

## 5.4 Clamps and Pressure Seals

### 5.4.1

A conceptual design for a clamp is discussed in section 3.5.8. The only development work required would be standard sizes to suit the flat cable sizes selected.

### 5.4.2 Pressure Seals

A conceptual design for a pressure seal is shown in Figure 5.4.2. This seal would be potted during harness assembly. Again, work is involved to specify standard sizes. Also, the cut-out radius, flange reach and boltdown methods should be checked against those shown in Figure 5.4.2 for suitability to the airframe material under consideration.

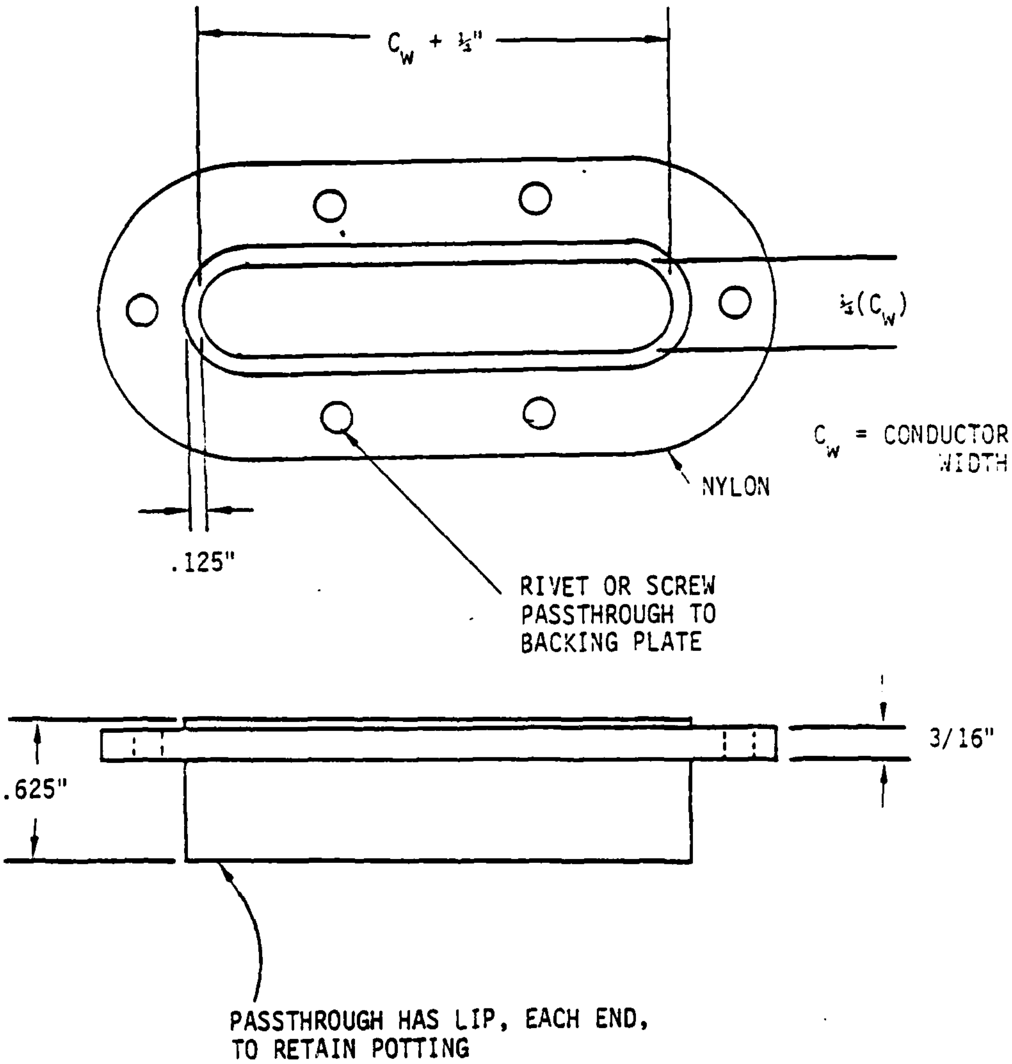



FIGURE 5.4.2

CONCEPTUAL DESIGN FOR A
FLAT CABLE PRESSURE SEAL FIXTURE

## 5.5 Manufacturing Buildup and Installation Tools

### 5.5.1 Cable Marking Machinery

As mentioned in section 3.5.7.3, physical attachment of coded cable and harness information could be fulfilled by the methods of hot stamping and imprinting. Existing round wire marking equipment should be easily modified by (1) altering the printing head from a concave to a flat configuration, (2) increasing the width of the 'mouth' of the equipment as necessary for the wider cable.

An additional possibility for marking would be the use of laser marking techniques. These techniques are relatively new, and are not yet fully implemented for cable marking.

### 5.5.2 Flat Cable Cutters

Cutting equipment for flat cables is not a major concern, but a few considerations do need to be addressed. The use of conventional handheld sheet metal shears is not recommended, due to the ragged and turned edges that result. Stationary floor standing metal shears (hydraulic or foot operated) with a heavy cutting head and a clamp to hold the cable firmly are required to produce a clean cut. These are available to accomodate sheets which are several feet wide and could be used as is, although these existing units would have considerable extra room for flat cable cutting.

### 5.5.3 Bend Preforming Jigs

A typical harness assembly station is shown in Figure 4.9.1. The bend preforming jig is designed to be swiveled and locked to the angle required, as well as sliding up and down the length of the table to the location desired.

The creasing mechanism of the jig should be a rounded tongue and groove type which clamps down and puts a partial fold in the cable. The bend radius would be a function of the cable mechanical properties as well as the particular cable size being formed. The jig should have either (a) interchangeable heads, or (b) a rotating wheel of tongue and groove heads of assorted sizes.

This part of the harness assembly station would readily lend itself to automation, although the automation phase might be postponed until harness assembly and installation methods have been refined. The tedious, repetitive action of bend preforming would be a labor intensive, error prone process if performed manually. Because of the relatively simple linear motion of the jig along the table, it should be an easy step to provide computer control of the jig.

### 5.5.4 Strippers

Carpenter Mfg. Co., Inc., Model 46A, should serve as a stationary stripper for an intial assembly area. Field stripping tools will also be necessary. These field tools should be manually operated for usage aboard a fueled aircraft. As the optimum method of field stripping will depend on the cable

final designs, no field stripping tools can be designed at this time. It would be most cost effective to perform field stripping with crude devices (e.g., razor blades and needle nose pliers) until the cable manufacturing methods have been refined. At that time, finalization of insulation types, adhesion methods and other factors will permit development of field stripping tools.

### 5.5.5 Hand Tools for Final Forming of Bends

Two models of these will be required.

(1) A version for the harness assembly shop area. This model can be 'clumsier' and heavier than the other one, but this advantage should be utilized to produce a more precise bend.

(2) A version for close quarters work during airframe installation. This model should be compact and lightweight to permit handy carrying around and maneuverability in close quarters.

The details of the head mechanism would be similar for both models, consisting of an appropriate size mandrel and a partial cylinder at a slight (0.25") distance from each other (see Figure 5.5.5.1). The cable could be slipped between the mandrel and partial cylinder at the open end. With a closing of the ratcheted handles, the flat cable would be pressed into the required bend. Replacable mandrels and cylinders would be required for different bend radii and angle of bending.

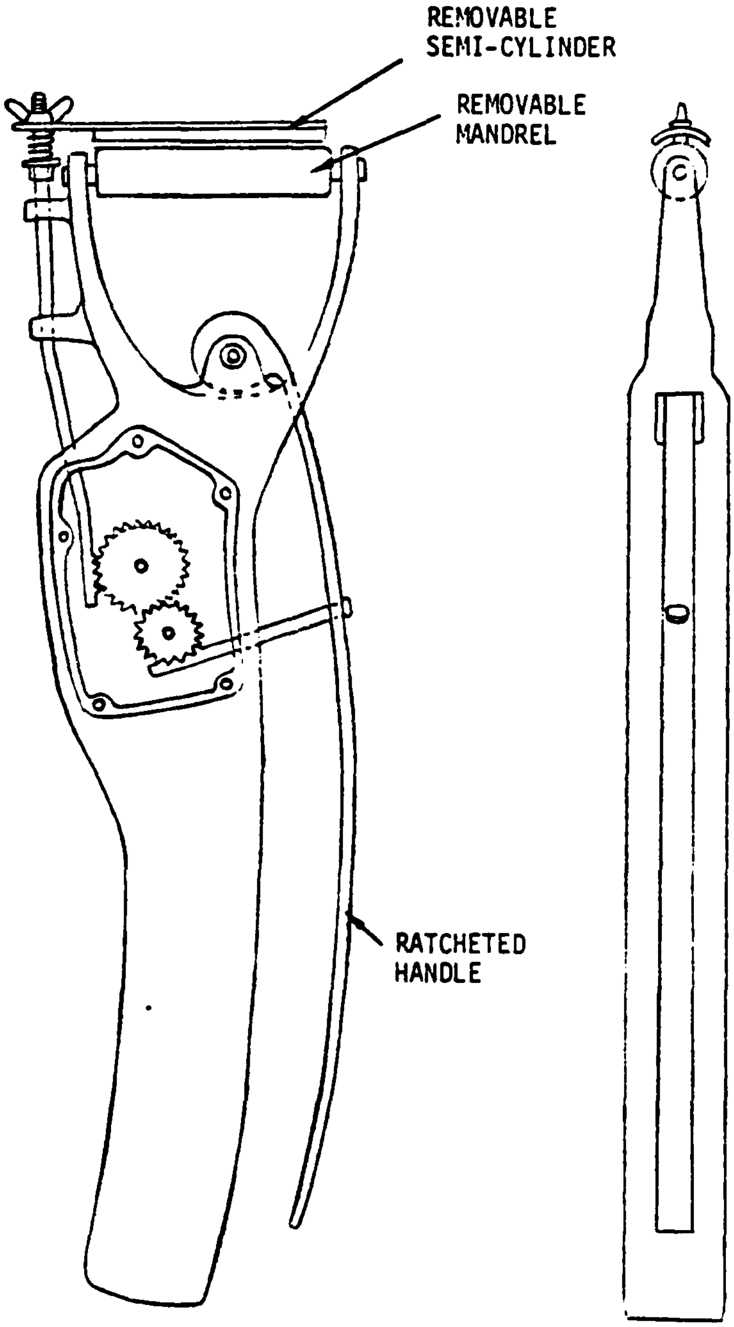



FIGURE 5.5.5.1
CONCEPTUAL DESIGN FOR
FLAT CABLE BEND FORMING HAND TOOL

# APPENDIX A

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| | |
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| MIL-W-25038 | Wire, electrical, high temperature and fire resistant, aircraft |
| MIL-C-49059 | Cable, electrical (flexible, flat, unshielded), (Flat conductor) general specification for |
| MIL-C-55543 | Cable, electrical flat multiconductor, flexible, unshielded |

<u>Military Standards</u>

| | |
|---|---|
| MIL-STD-454 | Standard general requirements for electronic equipment |
| MIL-STD-704 | Aircraft electronic power characteristics |

<u>Military Handbooks</u>

| | |
|---|---|
| MIL-HDBK-217C | Reliability prediction of electronic equipment |

<u>Federal Standards</u>

| | |
|---|---|
| QQ-C-502 | Copper rods and shapes; and flat products with finished edges (flat wires, strips and bars) |
| QQ-C-576 | Copper flat products with slit, slit and edge-rolled, sheared, sawed, or machined edges (plate, bar, sheet and strip) |

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# APPENDIX B

## FLAT CABLE CURRENT CAPACITY AND VOLTAGE DROP COMPUTER PROGRAMS

AD-A114 026 BOEING AEROSPACE CO SEATTLE WA F/G 10/2
FEASIBILITY STUDY OF A 270V DC FLAT CABLE AIRCRAFT ELECTRICAL P--ETC(U)
JAN 82 M J MUSGA, R J RINEHART N62269-81-C-0231
UNCLASSIFIED D182-10816-1 NADC-82023-60 NL

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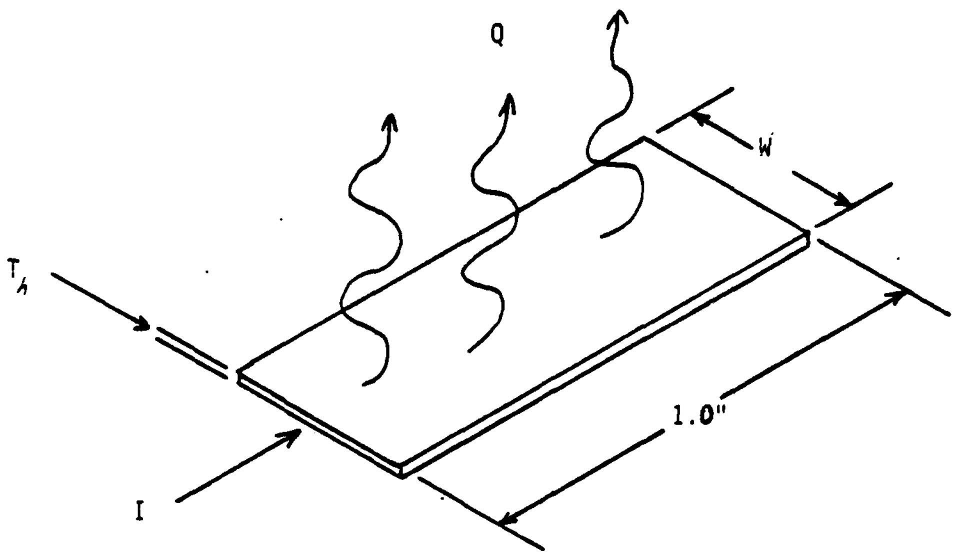



Figure B.1 Oblique View - Flat Conductor Cable

W = Conductor Width, Feet
$T_h$ = Conductor Thickness, Feet
I = Steady State Load Current, Amperes
Q = Rate of Heat Dissipation, BTU/HR-FT$^2$ - $^oF$

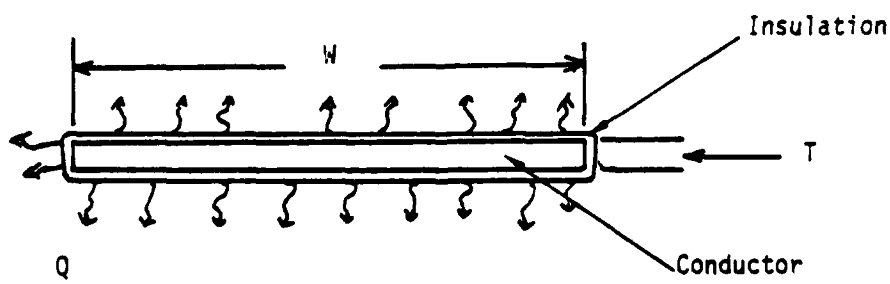



Figure B.2 Cross Section View - Flat Conductor Cable

Thermal Energy Balance

Heat In + Heat Generated = Heat Out + Heat Accumulated

At Steady State,

Heat In = 0

Heat Accumulated = 0

Therefore,

Heat Generated = Heat Out (1)

Heat Generated = $P = I^2 R$ (2)

where

P = Resistance Loss, Watts
I = Load Current, Amperes
R = Electrical Resistance, Ohms

Heat Out = $Q = H A \Delta T$ (3)

where

Q = Rate of Heat Transfer, BTU/HR
H = Heat Transfer Coefficient, BTU/HR $FT^2$ $^oF$
A = Conductor Surface Area, $FT^2$
$\Delta T$ = Temperature Difference Between Conductor and Ambient, $^oF$

Substituting (2) and (3) into (1),

$$I^2R = H A \Delta T (K) \quad (4)$$

K = Conversion Factor = .292875 Watt HR/BTU

$$A = 2(W + T_h)(1.0) \quad (5)$$

where

$W/T_h$ = Conductor Width to Thickness Ratio

$$\frac{1}{H} = \frac{1}{h_R + h_c} + \frac{T_I}{K_I}$$

where

$h_r$ = Radiative Heat Transfer Coefficient

$h_c$ = Free Convection Heat Transfer Coefficient

$T_I$ = Insulation Wall Thickness, FT

$K_I$ = Thermal Conductivity of Insulation, BTU/FT

Note: $\frac{T_I}{K_I} << \frac{1}{h_R + h_c}$

$$\therefore \quad H \cong h_R + h_c \tag{6}$$

$$R = P \frac{L}{A} \tag{7}$$

where

$R$ = Electrical Resistance, Ohms

$P$ = Conductor Resistivity, Ohm - Ft

$L$ = Conductor Length 1.0 Ft

$A$ = Conductor Cross Section, $Ft^2$

Substituting (5), (6) & (7) into (4) yields,

$$I^2 (\rho) \left(\frac{1.0}{2(W + T)(1.0)}\right) = (h_R + H_c) (2 (W + T_h)) \Delta T (K)$$

Simplifying and solving for I yields,

$$I = \left[\frac{(1.1715)(W + T_h)^2 (h_R + h_c) (\Delta T)}{(\rho)}\right]^{1/2} \tag{8}$$

This is for a single insulated wire; for a two wire system, the equation development would be similar.

$$\rho = \rho_o (1 + \alpha(T_2 - T_o)) \tag{9}$$

where

$\rho$ = Resistivity at $T_2$, OHM-FT

$\alpha$ = Temperature coefficient of resistance, $^oF^{-1}$

$\rho_o$ = Resistivity at $T_o$, OHM - FT

$T_2$ = Conductor Temperature, $^oF$

$T_o$ = Reference Temperature, $^oF$

PROGRAM FOR CURRENT CALCULATIONS.
(WRITTEN IN BOEING INTELLIGENT TERMINAL SYSTEM (BITS) FORTRAN)

```
      character config*12
      real rhoc
      dimension xsec (25)
      OPEN(6,FILE = 'PRINTER:')
      OPEN(7,FILE = 'AWGDAT.TEXT)
      I = 1
      READ (7,100)(XSEC(I),I = 1,10)
100   FORMAT (F7.6)
C RESISTIVITY OF COPPER @ 68 F (OHM-FT).
      RHOC = 5.74E-8
      ALPHA = .00214
      emsl = .8
      ems2 = .8
      cam = 2.0
1     IF (CAM .NE. 2.0) GO TO 2
      CONFIG = 'STACKED'
      GO TO 3
2     CONFIG = 'SIDE BY SIDE'
3     wtrato = 150.0
4     alt = 0.0
5     altx = alt * 1000.0
      write (6,101) config,wtrato,altx
101   format (1x,///,'configuration = ',a,/,'w/t ratio = ',f5.1,/,'alti
     1tude = ',f8.1,/)
      write (6,102)
102   format (1x,'ambient temp.',3x,'temp. rise',4x,'cond. x-section',
     14x,'current',/)
      x = 1.0/emsl
      y = 1.0/ems2
      f12 = 1.0/(x + y - 1.0)
      p = 10.0 ** (alt * (-.0189413))
      tamb = 50.0
6     deltat = 50.0
      tcond = tamb + deltat
      tmean = tamb + (deltat/2.0)
      rk = (133.0 + (.2355*tmean) + (4.605e-8*tmean)**2.77)*(1.0e-4)
      a = (tcond + 459.6)/100
      b = (tamb + 459.6)/100
      ft = 0.172*(a**4 - b**4)/deltat
      hrad = f12*ft
      x = tmean/68.7
      y = 6.4*tmean + 1980.0
7     i = 1
8     exsec = xsec(i)
      cthick =( sqrt(exsec/wtrato))/12.0
      cwidth = cthick * wtrato
      cukf = x - 52.15 + 1.0e+6 /y
      z = 459.6 + tmean
      rhof = .0862 * p * (460.0/z)
      grpr = 4.17e+8 * deltat *(cwidth*cam/2.0)**3 * rhof**2 * cukf/z
      hcon = ( rk * .81 * grpr**.25)/(cwidth*cam/2.0)
      if (cam .ne. 2.0) go to 9
      as = cam * (cwidth + 2.0 * cthick) * 1.05
      go to 10
```

```
9       as = cam * (cwidth + 0.5*cthick) * 1.05
10      hovl = (hrad + 0.5 * hcon) * as
        rl = (rhoc * 144.0)/exsec
        r2 = rl*(1.0 + (alpha * (tcond - 68.0)))
        amps = sqrt((hovl * deltat)/(6.82 * r2))
        write (6,103) tamb, deltat, exsec,amps
103     format(4x,f5.1,10x,f6.1,10x,f7.6,8x,f6.2)
        if (i .ge. 10)go to 11
        i = i + 1
        go to 8
11      if (deltat .ge. 150.0) go to 12
        deltat = deltat + 50.0
        go to 7
12      if (tamb .ge. 350.0) go to 13
        tamb = tamb + 100.0
        go to 6
13      if (alt .ge. 80.0) go to 14
        alt = alt + 10.0
        go to 5
14      IF (WTRATO .GE. 200.0) GO TO 15
        WTRATO = 200.0
        GO TO 4
15      if (cam .ge. 4.0) go to 16
        cam = 4.0
        GO TO 1
16      stop
        end
```

PROGRAM FOR VOLTAGE DROP CALCULATIONS (ALSO IN BITS FORTRAN)

```
      character config*12
      real rhoc,MALD,LEN
      dimension xsec (25)
      OPEN (6,FILE = 'PRINTER:')
      OPEN (7,FILE = 'AWGDAT.TEXT')
      i = 1
      READ (7,100)(XSEC(I),I = 1,10)
100   FORMAT (F7.6)
c resistivity of COPPER @ 68 f (ohm-ft).
      rhoc = 5.74e-8
      alpha =.00214
      ems1 = .8
      ems2 = .8
      cam = 2.0
      wtrato = 150.
      alt = 0.0
      MALD = 1.0
      config = 'stacked'
1     altx = alt * 1000.0
      write (6,101) config,wtrato,altx,MALD
101   format (1x,///,'configuration = ',a,/,'w/t ratio = ',f5.1,/,'alti
     1tude = ',f8.1,/,'MAX. ALL. LINE DROP = ',F3.1,/)
      write (6,102)
102   format (1x,'ambient temp.',3x,'temp. rise',4x,'cond. x-section',
     14x,'current',5x,'LINE LENGTH',/)
      x = 1.0/ems1
      y = 1.0/ems2
      f12 = 1.0/(x + y - 1.0)
      p = 10.0**(alt*(-.0189413))
      tamb = 120.0
2     i = 1
3     c = 1
      deltat = 100.0
      exsec = xsec(i)
      cthick = (sqrt(exsec/wtrato))/12.0
      cwidth = cthick*wtrato
4     tcond = tamb + deltat
      tmean = tamb + (deltat/2.0)
      rk =(133.0+(.2355 * tmean) + (4.605e-8 * tmean)**2.77) * (1.e-4)
      x = (tcond + 459.6)/100
      y = (tamb + 459.6)/100
      ft = 0.172 * (x**4 - y**4)/deltat
      hrad = f12 * ft
      x = tmean/68.7
      y = 6.4 * tmean + 1980.0
      cukf = x - 52.15 + 1.0e+6 /y
      x = 459.6 + tmean
      rhof = .0862 * p * (460.0/x)
      grpr = 4.17e+8 * deltat *(cwidth*cam/2.0)**3 * rhof**2 * cukf/x
      hcon = ( rk * .81 * grpr**.25)/(cwidth*cam/2.0)
      as = cam * (cwidth + 2.0 * cthick) * 1.05
      hov1 = (hrad + 0.5 * hcon) * as
      r1 = (rhoc * 144.0)/exsec
      r2 = r1*(1.0 + (alpha * (tcond - 68.0)))
```

```
      amps = sqrt((hovl * deltat)/(6.82 * r2))
      DELTAV = AMPS * R2
      LEN = MALD / DELTAV
      write (6,103) tamb, deltat, exsec,amps,LEN
103   format(4x,f5.1,10x,f6.1,10x,f7.6,8x,f6.2,7X,F8.4)
      DELTAT = DELTAT * 0.25
      if (c .gt. 3) go to 5
      C = C + 1
      go to 4
5     I = I + 1
      IF (I .LE. 10) GO TO 3
      IF (TAMB .LT. 300) THEN
         TAMB = 300
         GO TO 2
        ELSEIF (TAMB .EQ. 300) THEN
               TAMB = 400
               GO TO 2
        ELSE
         IF (MALD .LT. 4) THEN
            MALD = 4
            GO TO 1
           ELSEIF (MALD .EQ. 4) THEN
                  MALD = 6
                  GO TO 1
         ENDIF
      ENDIF
      stop
      end
```

# APPENDIX C

## Worksheet for Weight Tabulations and Component Weight Estimates

TABLE C.1

COMPONENT WEIGHTS

HIGH AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum.- [illegible] AWG | 2 | [illegible] | | [illegible] | SPEC: [illegible] TYPE I, CLASS I |
| | Insulated Wire-Copper- [illegible] AWG | - | [illegible] | | [illegible] | SPEC: TO BMS 13-[illegible] TYPE I, CLASS I |
| | Insulated Wire-Copper- 2/0 AWG | 2 | 7.0 | | 7.7 | SPEC: TO BMS 13-23 TYPE I, CLASS I |
| | Sleeving | | 77 | | [illegible] | SPEC: TO BMS 13-52 TYPE I, [illegible] I.D. = .50 |
| | Sleeving | | | | | |
| | Shielding | | 35 | | [illegible] | SPEC: [illegible] P.N. -[illegible] |
| | Shielding Ferrules | | | 2 | 0.1 | |
| | Terminal Lug | | | - | 0.2 | |
| | Splice | | | - | 0.2 | |
| | Conntr/Backshell | | | 1 | 1.2 | FIRE WALL |
| | Clamp | | | 68 | 5.- | BACC10EP-15 |
| | Press. Seal/Potting | | | 1 | NEG. | SEAL P.N.: BAC [illegible] WITH FITTING. INSTALL AND POT PER BAC [illegible] |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | 1 | 0.6 | |
| | Shield Plate | | | 2 | 0.6 | NEW |

TOTAL WEIGHT = 52.7

TABLE C.2
COMPONENT WEIGHTS
MEDIUM AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper- 4 AWG | 2 | 76 | | 17.2 | SPEC: TO BMS 13-51 TYPE I, CLASS I |
| | Insulated Wire-Copper- | | | | | |
| | Sleeving | | 9 | | 0.1 | SPEC: TO BMS 13-52 TYPE I, NOM.I.D.= .50 |
| | Sleeving | | | | | |
| | Shielding | | 76 | | 2.9 | SPEC: TO BAC 5103 P.N. -1 |
| | Shielding Ferrules | | | 2 | 0.1 | |
| | Terminal Lug | | | 2 | NEG. | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 1 | 0.4 | |
| | Clamp | | | 62 | 0.7 | P.N.: BACC10DX-16 |
| | Press. Seal/Potting | | | 1 | 0.4 | SEAL P.N.: BAC 04-532 INSTALL AND POT PER BAC 5103 |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | 1 | 0.5 | |

TOTAL WEIGHT = 22.3

TABLE C.3

COMPONENT WEIGHTS

LOW-1 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper- 8 AWG | 2 | 90 | | 13.2 | SPEC: TO BMS 13-51 TYPE I, CLASS I |
| | Insulated Wire-Copper- | | | | | |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | 90 | | 2.9 | SPEC: TO BAC [illegible] P.N.: -F |
| | Shielding Ferrules | | | 2 | 0.1 | |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 2 | 0.5 | |
| | Clamp | | | 72 | 0.4 | P.N.: BACC10DK-8A |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL WEIGHT = 17.1

TABLE C.4

COMPONENT WEIGHTS

LOW-2 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper-14 [illegible] | 2 | 36 | | 0.97 | SPEC: [illegible] 27500-14-[illegible] |
| | Insulated Wire-Copper- | | | | | |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | 36 | | [illegible].23 | SPEC: [illegible] P.N.: -23 |
| | Shielding Ferrules | | | 2 | 0.05 | |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 2 | 0.65 | |
| | Clamp | | | 28 | 0.04 | P.N.: BACC10DR6 |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL WEIGHT = 1.99

TABLE C.5

COMPONENT WEIGHTS

HIGH AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum.- 3/0 AWG | 1 | 60 | | 12.9 | SPEC: TO BMS 13-[illegible] TYPE I, CLASS I |
| | Insulated Wire-Copper- 6 AWG | 2 | 13 | | 3.4 | SPEC: TO BMS 13-51 TYPE I, CLASS I |
| | Insulated Wire-Copper- 2/0 AWG | 1 | 7.0 | | 5.7 | SPEC: TO BMS 13-23 TYPE , CLASS I |
| | Sleeving | | 77 | | 0.6 | SPEC: TO BMS 13-[illegible] NOM.I.D.= .50, TYPE I |
| | Sleeving | | | | | |
| | Shielding | | 77 | | [illegible] | SPEC: TO BAC [illegible] P.N.: [illegible] |
| | Shielding Ferrules | | | 2 | 0.1 | |
| | Terminal Lug | | | 2 | 0.1 | |
| | Splice | | | 2 | 0.1 | |
| | Conntr/Backshell | | | 1 | 1.2 | FIRE[illegible] |
| | Clamp | | | 63 | 1.7 | P.N.: BACC10EP-8 |
| | Press. Seal/Potting | | | 1 | NEG. | SEAL P.N.: BACS-531 NYLON FITTING. INSTALL AND POT PER BAC 5108 |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | 1 | 0.6 | |
| | Shield Plate | | | | | |

TOTAL WEIGHT = 27.4

TABLE C.6

COMPONENT WEIGHTS

MEDIUM AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper- 6 AWG | 1 | 76 | | 3.6 | SPEC: TO BMS 13-51 TYPE I, CLASS I |
| | Insulated Wire-Copper- | | | | | |
| | Sleeving | | 9 | | NEG. | SPEC: TO BMS 13-52 TYPE I, NOM.I.D.= .25 |
| | Sleeving | | | | | |
| | Shielding | | 9 | | 0.2 | SPEC: TO BAC [illegible] P.N.: -33 |
| | Shielding Ferrules | | | 2 | 0.1 | |
| | Terminal Lug | | | 1 | NEG. | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 1 | 0.- | |
| | Clamp | | | 62 | 0.2 | P.N.: BACC10DK-5 |
| | Press. Seal/Potting | | | 1 | 0.- | SEAL P.N.: BAC S4531 |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL WEIGHT = 9.9

TABLE C.7

COMPONENT WEIGHTS

LOW-1 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper- 3 AWG | 2 | 90 | | 13.2 | SPEC: TO BMS 13-51 TYPE I, CLASS I |
| | Insulated Wire-Copper- | | | | | |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | | | | |
| | Shielding Ferrules | | | | | |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 2 | 0.5 | |
| | Clamp | | | 72 | 0.2 | P.N.: BACC10DK-4 |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL WEIGHT = 13.9

TABLE C.8

COMPONENT WEIGHTS

LOW-2 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper- #18 AWG | 1 | 36 | | .25 | Spec.: to M81381/12-18-X |
| | Insulated Wire-Copper- | | | | | |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | | | | |
| | Shielding Ferrules | | | | | |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 2 | .65 | |
| | Clamp | | | 28 | .02 | BACC10DR6 |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL WEIGHT = .92

TABLE C.9

COMPONENT WEIGHTS

HIGH AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum.3.95"x.026" | 2 | 61 | | 19.4 | 150 C Rating |
| | Insulated Wire-Copper-1.41"x.009" | 4 | 19 | | 4.9 | 200 C Rating |
| | Insulated Wire-Copper-#2 Round | 2 | .75 | | 0.5 | Spec.: to EMS 13-28 Type I, Class I |
| | | | | | | |
| | Sleeving | | | | | |
| | Shielding | | | | | |
| | Shielding Ferrules | | | 2 | 0.3 | New |
| | Terminal Lug | | | | | |
| | Splice | | | 4 | 0.4 | Amp Termi-Foil |
| | Conntr/Backshell | | | 1 | 1.2 | New- Firewall |
| | Clamp | | | 68 | 3.4 | New |
| | Press. Seal/Potting | | | 1 | Neg | New |
| | Terminal Block | | | 1 | 0.8 | New |
| | RFI Stuffing Tube | | | 1 | 0.6 | New |
| | Shield Plate | | | 1 | 0.3 | New |

TOTAL Weight = 42.0

TABLE C.10

COMPONENT WEIGHTS

MEDIUM AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | ~~Insulated Wire-Alum.~~ | | | | | |
| | Insulated Wire-Copper-1.41"x.009" | 2 | 79 | | 10.2 | New- 200 C Rating |
| | ~~Insulated Wire-Copper- #6 Round~~ | ~~2~~ | ~~.75~~ | | 0.2 | Spec.: to BMS 13-28 Type I, Class I |
| | Sleeving | | 9' | | 0.1 | BMS 13-52 TypeI Nom. ID = .75" |
| | Sleeving | | | | | |
| | Shielding | | 79 | | 2.9 | New |
| | Shielding Ferrules | | | 2 | 0.2 | New |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 1 | 0.4 | New |
| | Clamp | | | 62 | 0.4 | New |
| | Press. Seal/Potting | | | 1 | Neg. | New |
| | Terminal Block | | | 1 | 0.1 | New |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | 1 | 0.3 | New |

TOTAL Weight = 14.5

TABLE C.11

COMPONENT WEIGHTS

LOW-1 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper- 1.41"x.009" | 2 | 91 | | 11.6 | 105 C Rating |
| | Insulated Wire-Copper- #9 Round | 2 | .75 | | 0.1 | Spec.: to BMS 13-51 |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | 91 | | 2.9 | New |
| | Shielding Ferrules | | | 2 | 0.2 | New |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 2 | 0.5 | |
| | Clamp | | | 72 | 0.5 | New |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | 2 | 0.3 | New |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL Weight = 16.1

TABLE C.12

COMPONENT WEIGHTS

LOW-2 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper-.47"x.003" | 2 | 38 | | 0.76 | New 105 C Rating |
| | Insulated Wire-Copper-18 AWG | 2 | .75 | | .04 | |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | 38 | | .28 | New |
| | Shielding Ferrules | | | 2 | .10 | New |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 2 | .65 | |
| | Clamp | | | 28 | .07 | BACC10DR6 |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | 2 | .18 | New |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL Weight = 2.08

TABLE C.13

COMPONENT WEIGHTS

HIGH AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum.3.10"x.021" | 1 | 61 | | 6.4 | New 150 C Rating |
| | Insulated Wire-Copper-#2 Round | 1 | .75 | | 0.2 | Spec.: to EMS 13-28 Type I, Class 1 |
| | Insulated Wire-Copper-1.41"x.009" | 2 | 19 | | 2.5 | New 200 C Rating |
| | Insulated Wire-Copper-2.8"x.019 | 1 | 7 | | 1.6 | New 260 C Rating |
| | Sleeving | | 73 | | 1.3 | EMS 13-52 Type I Nom. ID = 1.25 |
| | Shielding | | 73 | | 3.0 | New |
| | Shielding Ferrules | | | 2 | 0.3 | New |
| | Terminal Lug | | | | | |
| | Splice | | | 2 | 0.1 | New |
| | Conntr/Backshell | | | 1 | 1.2 | New - Firewall |
| | Clamp | | | 68 | 3.4 | New |
| | Press. Seal/Potting | | | 1 | Neg. | New |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | 1 | 0.6 | New |
| | Shield Plate | | | | | |

TOTAL Weight = 20.7

TABLE C.14

COMPONENT WEIGHTS

MEDIUM AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper- 1.41"x.009" | 1 | 79 | | 5.1 | New 200 C Rating |
| | Insulated Wire-Copper-#6 Round | 1 | .75 | | 0.1 | Spec.: to EMS 13-28 Type I, Class I |
| | Sleeving | | 9 | | 0.1 | EMS 13-52 Type I Nom ID = .75 In. |
| | Sleeving | | | | | |
| | Shielding | | 9 | | 0.2 | New |
| | Shielding Ferrules | | | 2 | 0.2 | New |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 1 | 0.- | |
| | Clamp | | | 62 | 0.4 | New |
| | Press. Seal/Potting | | | 1 | Neg. | New |
| | Terminal Block | | | 1 | 0.1 | New |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL WEIGHT = 7.0

TABLE C.15

COMPONENT WEIGHTS

LOW-1 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper-1.41"x.009" | 2 | 91 | | 11.6 | New 125 C Rating |
| | Insulated Wire-Copper-#8 Round | 2 | .75 | | 0.1 | Spec.: to BMS 13-28 Type I, Class I |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | | | | |
| | Shielding Ferrules | | | | | |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 2 | 0.5 | |
| | Clamp | | | 72 | 0.5 | New |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | 2 | 0.2 | New |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL WEIGHT = 12.9

TABLE C.16

COMPONENT WEIGHTS

LOW-2 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | WEIGHT (LBS) | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper-.47" x .003" | 1 | 38 | | 0.38 | New 125 A Rating |
| | Insulated Wire-Copper-#18 AWG | 2 | .75 | | .02 | M81381/12-18-n |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | | | | |
| | Shielding Ferrules | | | | | |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 2 | 0.65* | |
| | Clamp | | | 28 | .07 | New |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | 2 | .17 | New |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL WEIGHT = 1.29

TABLE C.17

COPPER FLAT CABLE WEIGHTS

6.0 MILS INSULATION, $\rho$ = 1.78 g/cc

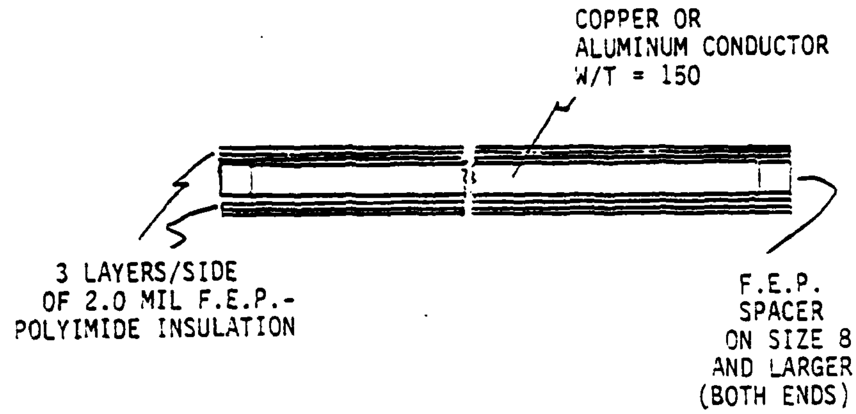
| Conductor Width Inches | Conductor Thickness Inches | Conductor Weight lb/Ft | Insulation Weight lb/Ft | Total Weight lb/Ft |
|---|---|---|---|---|
| .378 | .00252 | .003671 | .003635 | .007306 |
| .473 | .00315 | .005742 | .004520 | .01027 |
| .535 | .00357 | .007361 | .005098 | .01246 |
| .672 | .00448 | .01160 | .006375 | .01798 |
| .832 | .00554 | .01776 | .007867 | .02563 |
| 1.070 | .00700 | .02833 | .009899 | .03823 |
| 1.412 | .00942 | .05126 | .01327 | .06454 |
| 1.779 | .01186 | .08132 | .01669 | .09801 |
| 2.242 | .01494 | .1291 | .02101 | .1501 |
| 2.798 | .01865 | .2011 | .02619 | .2273 |
| 3.103 | .02069 | .2474 | .02904 | .2765 |
| 3.509 | .02340 | .3165 | .03282 | .3493 |
| 3.950 | .02633 | .4008 | .03693 | .4378 |
| 4.433 | .02955 | .5049 | .04144 | .5463 |
| 4.990 | .03330 | .6404 | .04663 | .6870 |

TABLE C.18

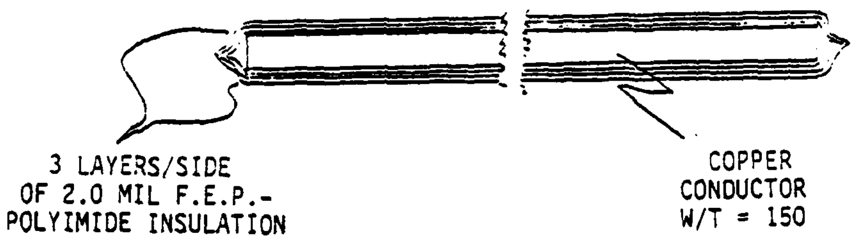
ALUMINUM FLAT CABLE WEIGHTS

6.0 MILS INSULATION, $\rho$ = 1.78 g/cc

| Conductor Width Inches | Conductor Thickness Inches | Conductor Weight lb/Ft | Insulation Weight lb/Ft | Total Weight, lb/Ft |
|---|---|---|---|---|
| 1.779 | .01186 | .02470 | .01669 | .04139 |
| 2.242 | .01494 | .03920 | .02101 | .06021 |
| 2.798 | .01865 | .06108 | .02619 | .08727 |
| 3.103 | .02069 | .07514 | .02904 | .1042 |
| 3.509 | .02340 | .09611 | .03282 | .1289 |
| 3.950 | .02633 | .1217 | .03693 | .1587 |
| 4.433 | .02955 | .1533 | .04144 | .1948 |
| 4.990 | .03330 | .1945 | .04663 | .2411 |

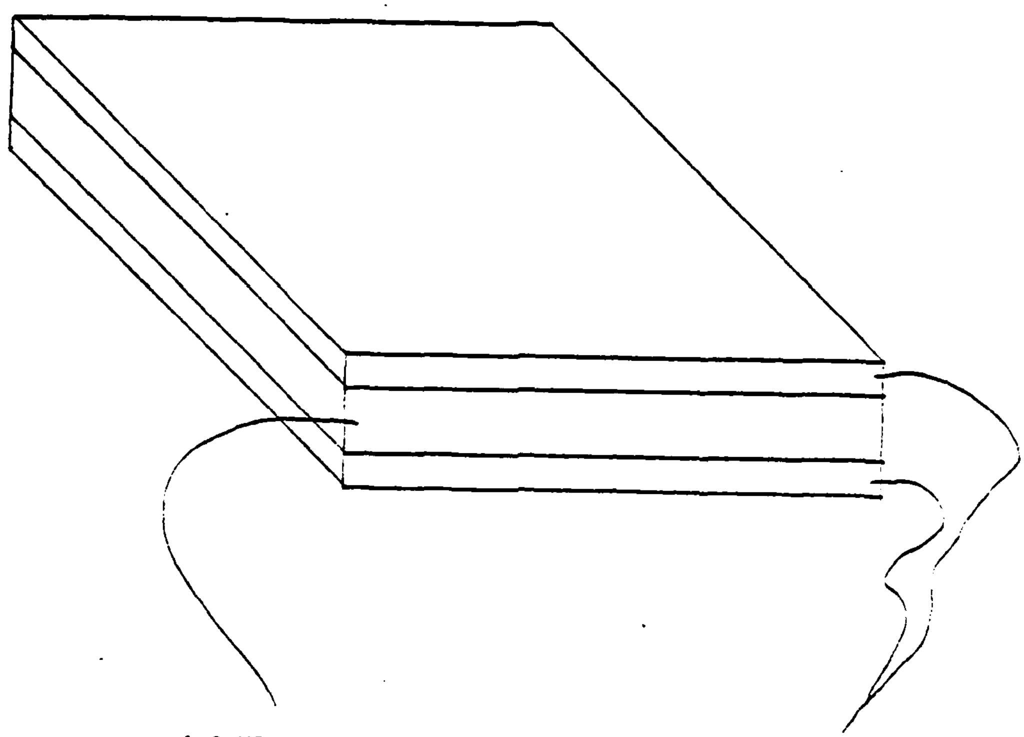



CROSS SECTION VIEW -
SIZE 8 AND LARGER FCC CABLE




CROSS SECTION VIEW -
SIZE 10 and SMALLER FCC CABLE

FIGURE C.1




TOTAL THICKNESS = 2.0 MIL
OVERALL DENSITY = 1.78g/cc

FIGURE C.2

TYPICAL F.E.P.-P.I. INSULATION LAYER

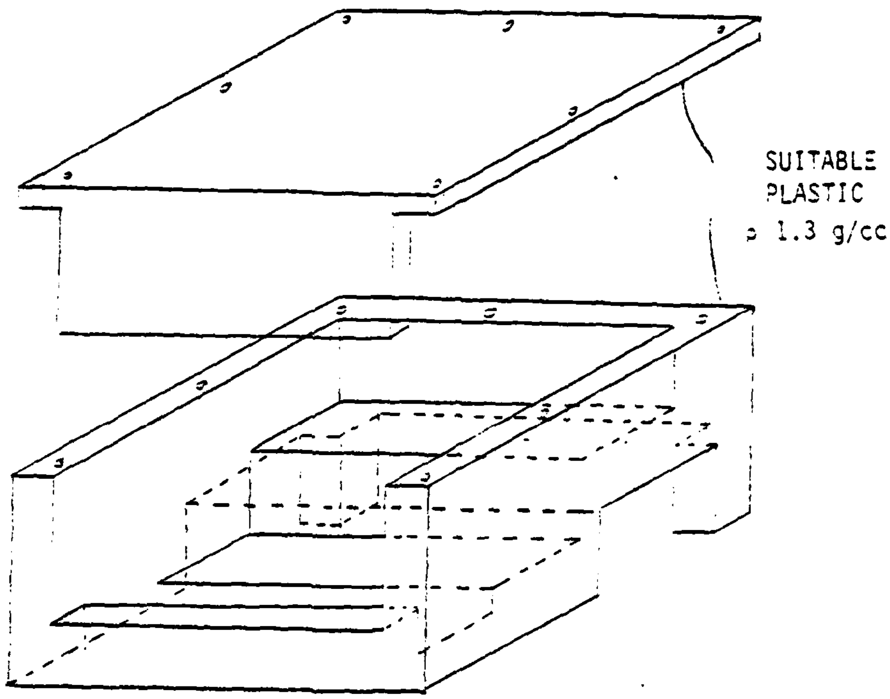



FIGURE C.3

FLAT CABLE TRANSITION TERMINAL BLOCK (CONTACTS NOT SHOWN)

TABLE C.19

TRANSITION TERMINAL

BLOCK WEIGHTS

| Wire Width In. | Terminal Opening In. | 1 Cond. Block Wt. lb. | 2 Cond. Block Wt. lb. |
|---|---|---|---|
| 0.378 | 0.578 | 0.050 | 0.085 |
| 0.473 | 0.673 | 0.054 | 0.089 |
| 0.535 | 0.735 | 0.056 | 0.092 |
| 0.672 | 0.872 | 0.060 | 0.098 |
| 0.832 | 1.032 | 0.066 | 0.106 |
| 1.050 | 1.250 | 0.073 | 0.115 |
| 1.412 | 1.612 | 0.085 | 0.132 |
| 1.779 | 1.979 | 0.097 | 0.148 |
| 2.242 | 2.442 | 0.113 | 0.169 |
| 2.798 | 2.998 | 0.131 | 0.194 |
| 3.103 | 3.303 | 0.142 | 0.208 |
| 3.509 | 3.709 | 0.155 | 0.226 |
| 3.950 | 4.150 | 0.170 | 0.245 |
| 4.433 | 4.633 | 0.186 | 0.266 |
| 4.990 | 5.190 | 0.204 | 0.291 |

AMP
AMP INCORPORATED
HARRISBURG, PA., U.S.A.

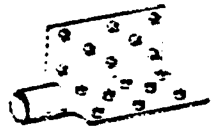
# A-MP* TERMI-FOIL* HAND TOOLS

| IS 1710 | |
|---|---|
| RELEASED | 1-29-62 |
| REVISED | 1-27-69 |

DOUBLE-FACED TERMINAL

(FIG. A)

DOUBLE-FACED TERMINAL (LONG TONGUE

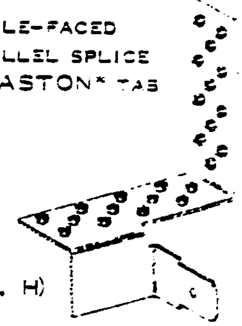


(FIG. B)

DOUBLE-FACED PARALLEL SPLICE

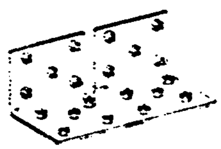
(FIG. C)

DOUBLE-FACED PARALLEL SPLICE W/FASTON* TAB



(FIG. H)

DOUBLE-FACED BUTT SPLICE

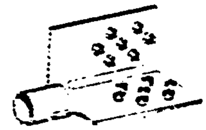


(FIG. D)

SINGLE-FACED TERMINAL

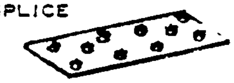
(FIG. E)

DOUBLE-FACED CENTER OR END TAP TERMINAL



(FIG. F)

SINGLE-FACED BUTT SPLICE



(FIG. G)

| TERMINAL OR SPLICE PART NO. & STYLE | NO. OF CRIMPS REQ'D | FOIL CRIMP TOOLING | | | SOLISTRAND* CRIMPING TOOLS | | | |
|---|---|---|---|---|---|---|---|---|
| | | DIES F/HAND TOOL 69175-1 OR PNEU. TOOL HEAD† 69263-1 | HAND TOOL (69175-1) WITH DIES INSTALLED | DIE CODE | WIRE SIZE | TOOL NO. | ALTERNATE TOOL PNEU. TOOL 69005 | ALTERNATE TOOL PNEU. TOOL 69010 |
| 50682 (FIG. B) | 8 | 69177-1 | 69288-1 | D | 8 | 69355 | —— | 38394 DIES |
| 329254 (FIG. A) | 1 | 69177-1 | 69288-1 | D | 12-10 | 49935 | 300454 DIES | 300583 DIES |
| 329255 (FIG. E) | 1 | 69176-1 | —— | S | 16-14 | | | |
| 329656 (FIG. C) | 1 | 69177-1 | 69288-1 | D | —— | —— | —— | —— |
| 329657 (FIG. D) | 2 | 69177-1 | 69288-1 | D | —— | —— | —— | —— |
| 329860 (FIG. A) | 1 | 69177-1 | 69288-1 | D | 16-14 | 49935 | 300454 DIES | 300583 DIES |
| 330003 (FIG. B) | 3 | 69177-1 | 69288-1 | D | 12-10 | | | |
| 330004 (FIG. B) | 5 | 69177-1 | 69288-1 | D | 12-10 | | | |
| 330005 (FIG. B) | 6 | 69177-1 | 69288-1 | D | 12-10 | | | |
| 330716 (FIG. F) | 1 | 69177-1 | 69288-1 | D | 12-10 | | | |
| 332063•(FIG. G) | 2 | 69176-1 | 69741 | S | —— | —— | | |
| 332510 (FIG. H) | 1 | 69177-1 | 69288-1 | D | —— | —— | —— | —— |

† USED IN PNEUMATIC TOOL NO. 69010 •MAX. FOIL THICKNESS .015

The Tools and Dies listed above are used to crimp A-MP Single and Double-Faced TERMI-FOIL Terminals and Splices onto Foil .001" to .030" thick.

Refer to the table to select the TERMI-FOIL Terminal or Splice style to use. The table also contains information relative to the number of crimps required for the TERMI-FOIL Terminal as well as suggested tooling for Terminals containing the SOLISTRAND Wire Barrel.

Die insertion procedure is described in Para. 1 for Tool No. 69175-1, which is sold without Dies. If Dies are removed from Tools 69288-1 or 69741 for any reason, make sure that they are installed as described in Para. 1.1

## 1. PROCEDURE FOR HAND TOOLS

### 1.1 INSERTING DIES

(a) To open Crimping Jaws, close Handles until CERTI-CRIMP* Ratchet releases. Note that once Ratchet is engaged, Handles cannot be opened until they are fully closed.

(b) Remove Roll Pins from Crimping Jaws.

(c) Place Dies in Tool Jaws and replace Roll Pins.

NOTE: Each Die Set consists of two halves. See Figure 2. Both halves are stamped with Code Letters. Letter "S" identifies Dies used to crimp Single-Faced Terminals. Letter "D" identifies Dies used to crimp Double-Faced Terminals. Be sure that Code Letters are located as shown in Figure 2.

## 1.2 Crimping Procedure

(a) For Single-Faced Terminals, completely cover lances with foil.

(b) For Double-Faced Terminals or Splices, place Foil between Faces of the Terminal or Splice and squeeze Faces together manually. See Figure 3.

(c) Open Tool Handles.

(d) Place Terminal and Foil between Dies. Make sure Terminal is completely covered by Dies. See Figure 4.
NOTE: Do not place Wire Barrel of Terminal between Dies.

(e) Close Handles until CERTI-CRIMP Ratchet releases.

(f) Remove crimped Terminal or Splice from Tool.

NOTE: When crimping Double-Faced Long Tongue Terminals, several crimps will be necessary. These crimps should be made with a slight overlap to make certain entire Face is crimped. Table on Page 1 lists number of crimps required.

(g) The Terminals or Splices, when correctly crimped, will appear as in Figure 5. Terminals or Splices may be crimped on Foil at any applicable position.
NOTE: If Dies are removed from Tool for any reason, make sure that they are replaced with code letters facing out as shown in Figure 4.

## 1.3 Wire Barrel Crimping

Crimp Terminal Wire Barrel with Tools listed on Page 1, or Tool with comparable "W" crimp. See Instruction Sheets referenced for procedure.

## 1.4 Crimping Tool Maintenance

Keep all Pins, Pivot Points and Bearing surfaces lubricated with a good grade S. A. E. No. 20 Motor Oil.

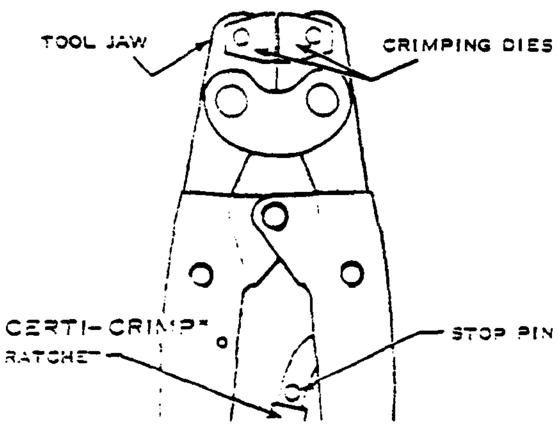



FIG. 1

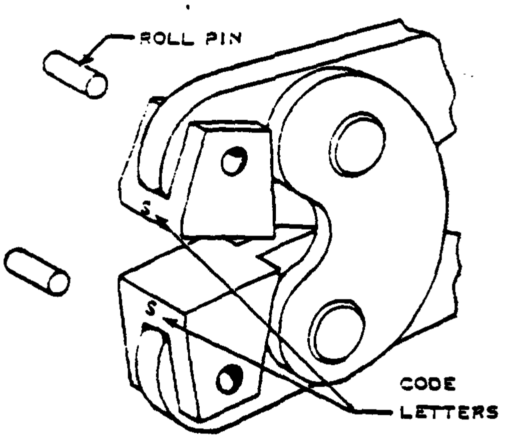



FIG. 2

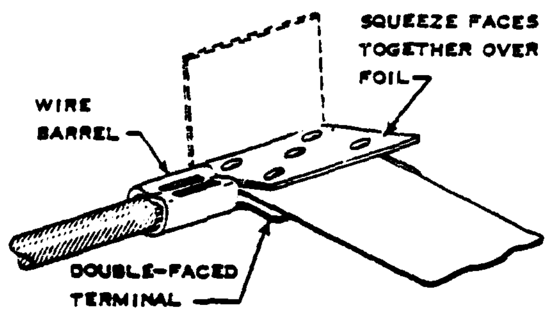



FIG. 3

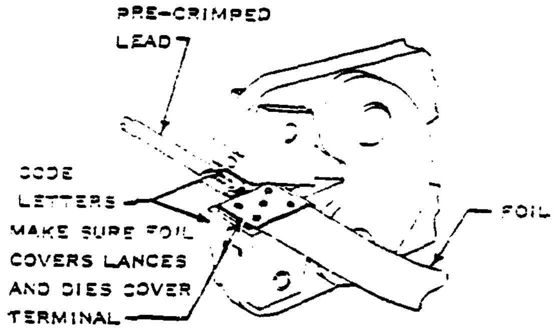



FIG. 4

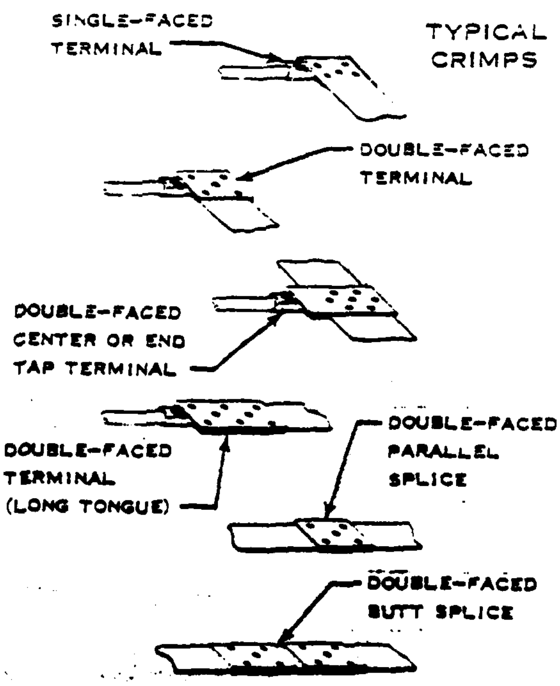



FIG. 5

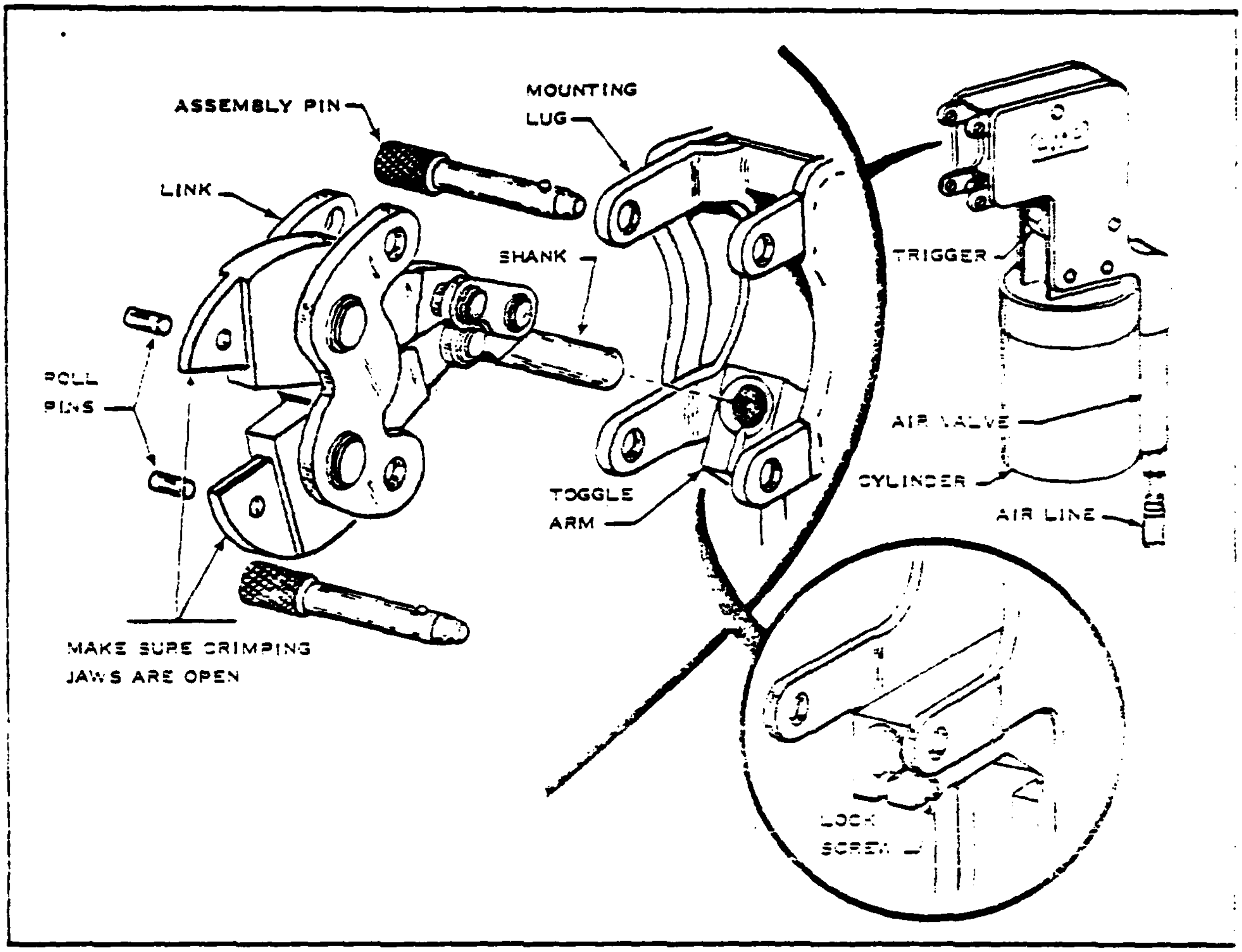



FIG. 6

2. PROCEDURE FOR PNEUMATIC TOOL 69010

2.1 CRIMPING HEAD INSTALLATION

(a) Make certain Air Supply is disconnected.
CAUTION: DO NOT OPERATE TOOL WITHOUT HAVING HEAD INSTALLED, AND LOCKSCREW TIGHTENED.

(b) Remove Assembly Pins from Mounting Lugs as shown in Figure 6.

(c) Loosen Lock Screw in Toggle Arm. Do not remove Lock Screw.

(d) Pull Toggle Arm forward as shown in Figure 6.

(e) Insert Shank of Crimping Head all the way into hole in Toggle Arm.

(f) Take up on Lock Screw enough to hold Head in place.

(g) Align Head as shown in Figure 7.

(h) After Head is aligned, lower it to provide access to Lock Screw on Toggle Arm. Tighten Lock Screw.

(i) Move Head back between Mounting Lugs as shown in Figure 7 and insert Assembly Pins. Do not connect air supply until dies are inserted. Always disconnect air supply before installing or removing Crimping Head or Dies.

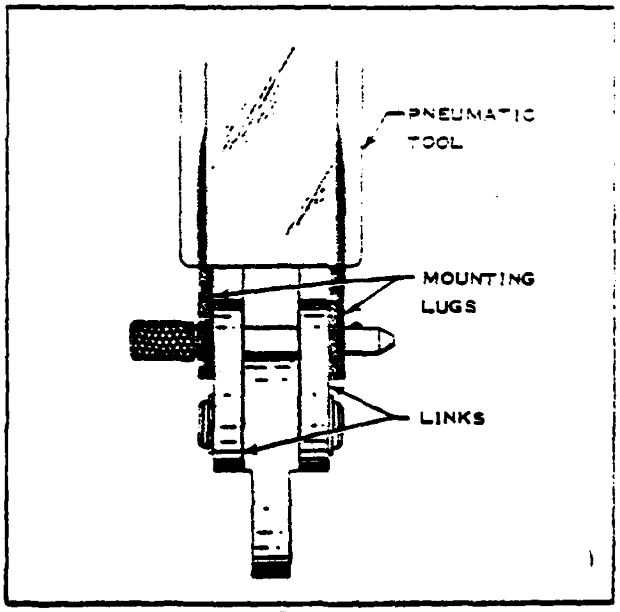



FIG. 7

2.2 INSERTING DIES

(a) Remove Roll Pins, see Figure 6, from Crimping Jaws.

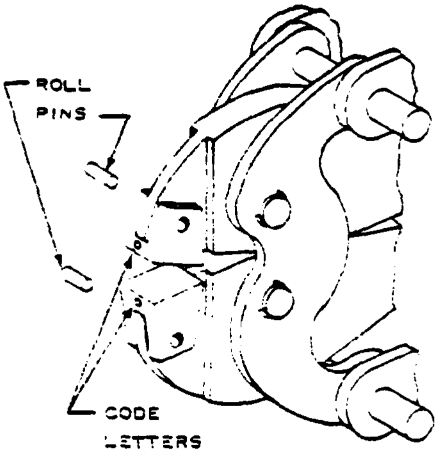



FIG. 8

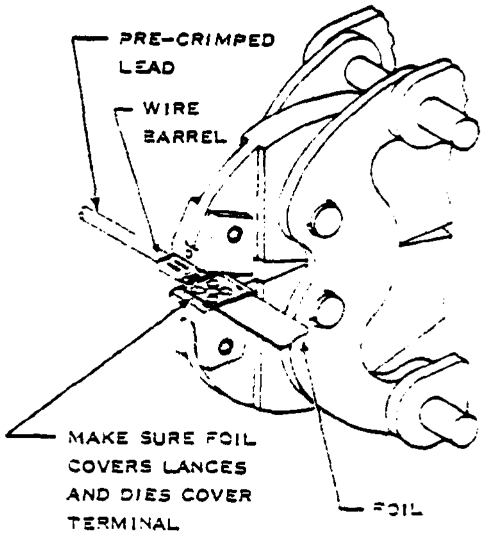



FIG. 10

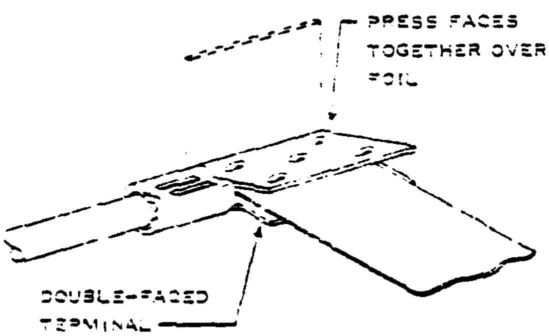



FIG. 9

(b) Place Dies in Jaws.

(c) Replace Roll Pins.
NOTE: Each Die Set consists of two halves. See Figure 8. Both halves are stamped with Code Letters. Letter "S" identifies Dies used to crimp Single-Faced Terminals. Letter "D" identifies Dies used to crimp Double-Faced TERMI-FOIL Terminals. Be sure that Code Letters are located as shown in Figure 8.

(d) To remove Dies, remove Roll Pins from Crimping Jaws, then remove Dies from Jaws.

## 2.3 CRIMPING PROCEDURE

(a) For Single-Faced Terminals, completely cover lances with foil.

(b) For Double-Faced Terminals or Splices, place Foil between Faces of Terminal and press Faces together manually. See Figure 9.

(c) Place Terminal and Foil between Dies. Make sure Terminal is completely covered by Dies. See Figure 10.
NOTE: Do not place Wire Barrel of Terminal between Dies.

(d) Press Trigger and hold it down until crimping stroke is completed.

(e) Release Trigger and remove crimped Terminal or Splice.
NOTE: When crimping Double-Faced Long Tongue Terminals, several crimps will be necessary. These crimps should be made with a slight overlap to make certain entire Face is crimped. Table on Page 2 lists number of crimps required.

(f) The Terminals or Splices, when correctly crimped, will appear as in Figure 5. Terminals or Splices may be crimped on Foil at any applicable position.

## 2.4 WIRE BARREL CRIMPING

Crimp Terminal Wire Barrel with Tools listed on Page 1, or Tool with comparable "W" crimp. See Instruction Sheets referenced for procedure.

## 2.5 CRIMPING HEAD MAINTENANCE

Keep all Pins, Pivot Points and Bearing surfaces lubricated with a good grade S. A. E. No. 20 Motor Oil.

# APPENDIX D

## Flat and Round Harness Reliability Calculations

Reliability Analysis - Flat Cable vs. Round Wire

NOTE: MIL-HDBK-217C was the major reference for this analysis.

A. Basic information and calculations for failure rate of high ampacity round wire harnesses.

1. Cable construction - cable is conventional round wire, #1 AWG aluminum spliced to #2 AWG copper, single conductor in metal airframe, double conductor for composite airframe, with 1 firewall connector (260 C) and terminal lugs at either end.

2. Terminations used - Copper to aluminum splice block
Conventional MIL-SPEC firewall connector
Conventional MIL-SPEC ring-tongue terminal lugs.

3. Operating conditions.
Temperature - 260 C maximum conductor temperature in engine area; 200 C maximum conductor temperature elsewhere.

Environmental service conditions - Airborne, uninhabited Fighter ($A_{uf}$)

Connector mating/unmating - 5 cycles/1000 hrs

Terminal lug mating/unmating - 2 cycles/1000 hrs

4. Connectors - Crimp, manual, standard quality factor

Calculation of failure rate due to connector at firewall.

From MIL-HDBK-217C, Table 2.11.1-1, "Prediction Procedure for Connectors", the failure rate model for a mated pair of connectors is:

$$\lambda_p = \lambda_b (\pi_E \times \pi_P \times \pi_K) \text{ FAILURES}/10^6 \text{ HOURS}$$

where:

$\lambda_b$ = base failure rate for the parts

$\pi_E$ = factor for environmental service condition

$\pi_P$ = factor for the number of active pins

$\pi_K$ = factor for connector mating/unmating cycles

From MIL-HDBK-217C, Table 2.11.1-5, the value for at 260 C is .00646 failures/10 hours.

Values in this instance:

$\pi_E$ = 10.0 for $A_{UF} + A_{IF}$

$\pi_P$ = 1.0 for 1 pin, 1.36 for 2 pins

$\pi_K$ = 2.0 for 0.5 - 5.0 cycles/1000 hours

Then

$\lambda_{P_1}$ = .00646 (10 x 1.0 x 2.0)

= .129 failures/$10^6$ hours
For high amp firewal connector mated pair in metal airframe (single pin)

$\lambda_{P_2}$ = .00646 (10 x 1.36 x 2.0)

= .175 failures/$10^6$ hours for high amp round wire firewall connector mated pair in composite airframe (two pins)

Calculation of failure rate due to connector, splice and lug crimp connections.

Copper to aluminum splice block is a two-ended crimp barrel.

Contacts are #2 pin and socket crimp type. Terminal lugs are conventional crimp type ring tongue terminals.

From MIL-HDBK-217C, page 2.13-1, the connection failure rate model is:

$$\lambda_P = \lambda_b (\pi_E \times \pi_T \times \pi_Q) \text{ FAILURES}/10^6 \text{ HOURS}$$

Where:

$\lambda_b$ = Base failure rate = .00026/crimp

$\pi_E$ = Environmental factor = 8.0

$\pi_T$ = Tool type factor = 2.0

$\pi_Q$ = Quality factor = 1.0

Or

$\lambda_P$ = .00026 (8.0 x 2.0 x 1.0)

= .00416 failures/$10^6$ hours/crimp

Metal Airframe

(.00416)(6 crimps/wire)(1 wire) = .025 failures/$10^6$ hours

Composite Airframe

(.00416)(6)(2 wires) = .050 failures/$10^6$ hours

For the mechanical compression stud-and-nut contacts on the lugs, the failure rate is assumed to be negligible.

Review of available literature and consultation with Boeing reliability specialists indicate the failure rate of the wire itself is also negligible, due to the passive nature of the wiring.

3. Basic Information and Calculations for Failure Rate of Medium Ampacity Round Wire Harness

1. Cable construction - Cable is conventional round wire, #6 AWG, with terminal lugs at the power rack and a conventional MIL SPEC connector on the L.C.S. pump in the wheel well. It is a one wire system in metal airframes and a two wire system in composite airframes.

2. Terminations Used - Conventional MIL-SPEC connector, 200 C conventional MIL-SPEC terminal lugs.

3. Operating Conditions:

   Temperature - 120 C average conductor temperature

   Environmental Service Conditions - Airborne, uninhabited, fighter ($A_{UF}$)

   Connector Mating/Unmating - 4 cycles/1000 hours

4. Connections - Crimp, manual, standard quality factor.

Calculations are similar to those for the high amp round wire; only the numbers are shown here.

Connector Failure Rate Calculations:

$\lambda_{p_1}$ = .00450 (10 x 1.0 x 2.0)

= .090 failures/$10^6$ hours

For medium ampacity connector round wire mated pair in metal airframe (single pin)

$\lambda_{p_2}$ = .00450 (10 x 1.36 x 2.0)

= .1224 failures/$10^6$ hours

For medium ampacity connector round wire mated pair in composite airframe (two pin)

Calculation of Failure Rate Due to Connector Contact and Lug Crimp Connections:

$\lambda_p$ = .00026 (3.0 x 2.0 x 1.0)

= .00416 failures/$10^6$ hours/crimp

Metal Airframe

(.00416)(2 crimps/wire)(1 wire)

= .00832 failures/$10^6$ hours

Composite Airframe

(.00416)(2)(2 wires)

= .0166 failures/$10^6$ hours

As for the high ampacity round wires, the failure rates for the mechanical compression lug contacts and for the wire itself is assumed negligible.

C. Basic Information and Calculations for Failure Rate of Low-1 (16.7A) Ampacity Round Wire Harness.

1. Cable Construction - Cable is conventional round wire, #3 AWG, with conventional MIL-SPEC connectors on both ends. It is a two wire system in both metal and composite airframe.

2. Terminations Used - Conventional MIL-SPEC connectors, 200 C rating

3. Operating Conditions:

Temperature - 100 C average conductor temperature

Environmental Service Conditions - Airborne, inhabited fighter ($A_{IF}$)

Connector Mating/Unmating - 10 cycles/1000 hours

4. Connections - Crimp, manual, standard quality factor

Connector Failure Rate:

$\lambda_p$ = (.00238)(10 x 1.36 x 3.0)(2 connectors)

= .118 failures/$10^6$ hours

Due to low-1 ampacity round wire harness connectors in both metal and composite aircraft.

Calculation of failure rate due to connector contact crimp conections:

$$\lambda_p = .00026\ (6.0 \times 2.0 \times 1.0)$$

$$= .00312 \text{ failures}/10^6 \text{ hours/crimp}$$

$$(.00312)(2 \text{ crimps/wire})(2 \text{ wires}) = .0125 \text{ failures}/10^6 \text{ hours}$$

Due to crimped connections on the low-1 ampacity run in both metal and composite airframes.

D. Basic Information and Calculations for Failure Rate of Low-2 (3.7A) Ampacity Round Wire Harness

1. Cable Construction - Cable is conventional round wire, #13 AWG, with conventional MIL-SPEC connectors on both ends. It is one wire system in metal airframes and a two wire system in composite airframes.

2. Terminations Used - Conventional MIL-SPEC connectors, 200 C rating.

3. Operating Conditions:

   Temperature - 100 C averagge conductor temperature

   Environmental Service Conditions - Airborne, inhabited fighter ($A_{IF}$)

   Connector Mating/Unmating - 10 cycles/1000 hours

4. Connections - Crimp, manual, standard quality factor.

Connector Failure Rate:

$$\lambda_{p_1} = (.00288)(10 \times 1.0 \times 3)(2 \text{ connectors})$$

$$= .0864 \text{ failures}/10^6 \text{ hours}$$

Due to low-2 ampacity connectors in metal airframes.

$$\lambda_{p_2} = (.00288)(10 \times 1.36 \times 3)(2 \text{ connectors})$$

$$= .118 \text{ failures}/10^6 \text{ hours}$$

Due to low-2 ampacity connectors in composite airframes.

Crimp Connection Failure Rate:

$$\lambda_{p_3} = .00026\ (6.0 \times 2 \times 1)(2 \text{ crimps/wire})$$

= .00624 failures/$10^6$ hours

Due to low-2 ampacity crimp connections in metal airframes.

= (.00624)(2 wires) = .0125 failures/$10^6$ hours

Due to low-2 ampacity crimp connections in composite airframes.

E. Basic Information and Calculations for Failure Rate of High Ampacity Flat Cable Harness

1. Cable construction is flat conductor, flat cable, 1.3 inches wide by .012 inches thick copper spliced to 2.24 inches wide by .015 inches thick aluminum. It is a one wire system in metal air frames and a two wire system in composite airframes, with 1 firewall connector (260 C) and terminal blocks at either end.

2. Terminations Used - Copper to aluminum crimp splice.

   Undeveloped crimp-type firewall connector
   Undeveloped bolt-down compression contact terminal blocks.

3. Operating Conditions:

   Temperature - 260 C maximum conductor temperature in engine area; 200 C maximum conductor temperature elsewhere.

   Environmental Service Conditions - Airborne, uninhabited fighter ($A_{UF}$)

   Connector Mating/Unmating - 5 cycles/1000 hours
   Terminal lug mating/unmating - 2 cycles/1000 hours

4. Connectors - All connections will be treated as crimp, manual, standard quality factor, for this reliability analysis.

   Calculation of failure rate due to connector at firewall

   (Same as round wire)

   $\lambda_{P_1}$ = .129 failures/$10^6$ hours for high ampacity flat cable firewall connector mated pair in a metal airframe.

   $\lambda_{P_2}$ = .175 failures/$10^6$ hours for high ampacity flat cable firewall connector in a composite airframe.

Calculation of failure rate due to splices, terminal block compression contacts and firewall crimp connections.

All of the above areas will be treated as conventional round wire crimp connections, due to a lack of available historical data.

From high ampacity round wire faiure rate calculations:

$\lambda_{P_1}$ = .0333 failures/$10^6$ hours due to splices and terminations on high ampacity flat cable harness in a composite airframe.

$\lambda_{P_2}$ = (.00416)(8)(2 wires)

= .0666 failures/$10^6$ hours

Due to splices and terminals on high ampacity flat cable.

As with round wire, the reliability of the wire itself is assumed negligible.

F. Basic Information and Calculations for Failure Rate of Medium Ampacity Flat Cable Harness

1. Cable Construction - Cable is 1.41 inches wide by .009 inches thick flat cable with a terminal block at the power rack and a terminal block with a conventional MIL-SPEC connector at the L.C.S. pump in the wheel well. It is a one wire system in a metal airframe and a two wire system in a

2. Terminations Used - Conventional MIL-SPEC connector, 200 C, Undeveloped bolt-down compression contact terminal blocks.

3. Operating Conditions:

   Temperature - 120 C average conductor temperature.

   Environmental Service Conditions - Airborne, uninhabited fighter ($A_{UF}$)

   Connector Mating/Unmating - 4 cycles/1000 hours

4. Connections - All connections will be treated as crimp, manual, standard quality factor.

Connector Failure Rate Calculations.

$\lambda_{P_1}$ = .00450 (10 x 1.0 x 2.0)

= .090 failures/$10^6$ hours

For medium ampacity flat cable harness connector (mated pair) in a metal airframe.

$\lambda_{P_2}$ = .1224 failures/$10^6$ hours

For medium ampacity flat cable harness connector (mated pair) in a composite airframe.

Calculation of Failure Rate Due to Connector Crimps and

Terminal Blocks.

$\lambda_{p_1}$ = (.00416)(3 crimps/wire)(1 wire)

= .0125 failures/$10^6$ hours

Due to crimps and terminations on medium ampacity flat cable harness in a metal airframe.

$\lambda_{p_2}$ = (.00416)(3)(2 wires)

= .0250 failures/$10^6$ hours

Due to crimps and terminations on medium ampacity flat cable harness in a composite airframe.

G. Basic Information and Calculations for Failure Rate of Low-I Ampacity Flat Cable Harness

1. Cable Construction - Cable is 1.41 inches wide by .009 inches thick flat cable with terminal blocks and conventional MIL-SPEC connectors at both ends. It is a two wire system in both metal and composite airframes.

2. Termination Used - Conventional MIL-SPEC connectors, 200 C Undeveloped bolt-down compression contact terminal blocks.

3. Operating Conditions:

   Temperature - 100 C average conductor temperature
   Environmental service conditions airborne, inhabited fighter ($A_{IF}$)

   Connector Mating/Unmating - 10 cycles/1000 hours

4. Connections - All connections will be treated as crimp, manual, standard quality factor.

Connector failure rate = (same as low-I round wire)

= .118 failures/$10^6$ hours

Due to low-I ampacity flat-cable harness connectors in both metal and composite airframes.

Failure rate calculations for crimped connector contacts and terminal block contacts.

$\lambda_p$ = (.00416)(4 crimps/wire)(2 wires)

= .0333 failures/$10^6$ hours

Due to crimps and terminal blocks on low-I ampacity flat cable harness in both metal and composite airframes.

H. Basic Information and Calculations for Failure Rate of Low-Z Ampacity Flat Cable Harness

1. Cable Construction - Cable is 0.47 inches wide by .003 inches thick flat cable with terminal blocks and conventional MIL-SPEC connectors on both ends. It is a one wire system in a metal airframe and a two wire system in a composite airframe.

2. Terminations Used - Conventional MIL-SPEC connectors, 200 C rating undeveloped bolt-down compression type terminal blocks.

3. Operating Conditions:

   Temperature - 100 C average conductor temperature

   Environmental Service Conditions - Airborne, inhabited fighter ($A_{IF}$)

   Connector Mating/Unmating - 10 cycles/1000 hours

4. Connections - All connections will be treated as crimp, manual, standard quality factor.

Connector Failure Rate = (same as low-Z round wire)

$\lambda_{P_1}$ = .0864 failures/$10^6$ hours

Due to low-Z ampacity flat cable harness connectors in a metal airframe.

$\lambda_{P_2}$ = .113 failures/$10^6$ hours

Due to low-Z ampacity flat cable harness connectors in a composite airframe.

Calculation of failure rate due to crimps and terminal blocks.

(.00416)(4 crimps/wire)(1 wire) = .0166 failures/$10^6$ hours

Due to crimps and terminal lugs on low-Z flat cable harness in a metal airframe.

(.00416)(4)(2 wires) = .0333 failures/$10^6$ hours

Due to crimps and terminal lugs on low-Z ampacity flat cable harness in a composite airframe.

# APPENDIX E

## Time and Cost Estimates for Maintenance Tasks

E.1 High Ampacity Harness - Round Wire Repair Times

| | Time, Minutes Metal A/C | Composite A/C |
|---|---|---|
| 1. Extract Harness (Ship to Facility) | 100 | 120 |
| 2. Sleeve/Shield Pullback | 5 | 8 |
| 3. Cut Out Damaged Section If Required | 13 | 13 |
| 4. Splice in New Section and Re-Insulate | 25 | 30 |
| 5. Replace Shield/Sleeve (Return to Aircraft) | 8 | 12 |
| 6. Re-Install Harness* | 143 | 176 |
| TOTAL | 294 | 359 |

*These times have been increased by 25% over the manufacturing times to allow for a non-production environment.

E.2 Medium Ampacity Harness Round Wire Repair Times

| | Time, Minutes Metal A/C | Composite A/C |
|---|---|---|
| 1. Extract Harness (ship to facility) | 80 | 95 |
| 2. Sleeve/Shield Pullback | 0 | 5 |
| 3. Cut Out Damaged Section If Required | 10 | 10 |
| 4. Splice In New Section Re-Insulate | 20 | 25 |
| 5. Replace Shield/Sleeve (Return to Aircraft) | 0 | 10 |
| 6. Re-Install Harness* | 81 | 95 |
| TOTAL | 191 | 240 |

*These times have been increased by 25% over the manufacturing times to allow for a non-production environment.

## Renewal Time Estimates

### E.3 High Ampacity Harness Flat Cable Renewal Time

| | Action | Time, Minutes Metal A/C | Time, Minutes Composite A/C |
|---|---|---|---|
| 1. | Cut Out Old Harness | 80 | 100 |
| 2. | Installation of New Harness* | 174 | 218 |
| | TOTAL | 254 | 318 |

*These times have been increased by 25% over the manufacturing times to allow for a non-production environment

### E.4 Medium Ampacity Harness Flat Cable Renewal Time

| | Action | Time, Minutes Metal A/C | Time, Minutes Composite A/C |
|---|---|---|---|
| 1. | Cut Out Old Harness | 65 | 85 |
| 2. | Installation of New Harness* | 118 | 149 |
| | TOTAL | 183 | 234 |

*These times have been increased by 25% over the manufacturing times to allow for a non-production environment

## Repair Time Estimates

### E.5 High Ampacity Harness - Flat Cable Repair Times

| | Action | Time, Minutes Metal A/C | Time, Minutes Composite A/C |
|---|---|---|---|
| 1. | Partial Extraction | 30 | 40 |
| 2. | Shielding/Sleeve Removal | 5 | 10 |
| 3. | Separate Conductors; Cut Out Damaged Section If Required | 5 | 15 |
| 4. | Splice in New Section and Re-Insulate | 20 | 30 |
| 5. | Replace Shield/Sleeve | 10 | 15 |

| | | | |
|---|---|---|---|
| 6. | Re-Install Harness | 50 | 65 |
| | TOTAL | 120 | 175 |

E.6 Medium Ampacity Harness Flat Cable Repair Times

| | Action | Time, Minutes Metal A/C | Composite A/C |
|---|---|---|---|
| 1. | Partial Extraction | 25 | 30 |
| 2. | Shielding/Sleeve Removal | 0 | 8 |
| 3. | Separate Conductors; Cut Out Damaged Section if Required | 4 | 13 |
| 4. | Splice in New Section and Re-Insulate | 15 | 15 |
| 5. | Replace Shield/Sleeve | 0 | 20 |
| 6. | Re-Install Harness | 45 | 60 |
| | TOTAL | 89 | 146 |

Maintenance Cost Estimates

E.7 High Ampacity Round Wire Repair Costs/$10^5$ Flight Hours

| | Item | Dollars Metal A/C | Composite A/C |
|---|---|---|---|
| 1. | Connector, Crimps and Terminals Failure Repair Costs*,** | 5.6 | 8.1 |
| 2. | Conductor Failure Repair Costs** | .1 | .1 |
| | Subtotal | 5.7 | 8.2 |
| | +10% for Materials | .6 | .8 |
| | TOTAL | 6.3 | 9.0 |

*Determined from failure rates in reliability analysis section

**Assuming a cost of $100/manhour for labor and overhead

E.8 Medium Ampacity Round Wire Repair Costs/$10^5$ Flight Hours

| | Item | Dollars Metal A/C | Dollars Composite A/C |
|---|---|---|---|
| 1. | Connectors, Crimps and Terminals Failure Repair Costs*,** | 3.5 | 5.0 |
| 2. | Conductor/Failure Repair Costs | .1 | .1 |
| | Subtotal | 3.6 | 5.1 |
| | +10% for Materials | .4 | .5 |
| | TOTAL | 4.0 | 5.2 |

*Determined from failure rate in reliability analysis section
**Assuming a cost of $100/manhour for labor and overhead

E.9 High Ampacity Flat Cable Maintenance Costs/$10^5$ Flight Hours (Option 1, Harness Renewal)

| | Item | Cost, Dollars Metal A/C | Cost, Dollars Composite A/C |
|---|---|---|---|
| 1. | Connectors, Crimps and Terminals - Failure Repair Costs | 5.9 | 8.7 |
| 2. | Complete Renewal of Harness-Manhours* | .1 | .1 |
| 3. | Harness Cost | .1 | .1 |
| | Subtotal | 6.1 | 8.4 |
| | +5% for Materials | .3 | .4 |
| | TOTAL | 6.4 | 9.3 |

*Determined from failure rate in reliability analysis section
**Assuming a cost of $100/manhour for labor and overhead

E.10 Medium Ampacity Flat Cable Maintenance Costs/$10^5$ Flight Hours (Option 1 - Harness Renewal)

| Item | Cost, Dollars Metal A/C | Composite A/C |
|---|---|---|
| 1. Connectors, Crimps and Terminals-Failure Repair Costs*,** | 3.7 | 5.3 |
| 2. Complete Renewal of Harness-Manhours** | .1 | .1 |
| 3. Harness Cost | .1 | .1 |
| Subtotal | 3.9 | 5.5 |
| +5% for Material Cost | .2 | .3 |
| TOTAL | 4.1 | 5.8 |

*Determined from failure rate in reliability analysis section
**Assuming a cost of $100/manhour for labor and overhead

E.11 High Ampacity Flat Cable Repair Costs/$10^5$ Flight Hours (Option 2 - In-Place Conductor Repair)

| Item | Cost, Dollars Metal A/C | Composite A/C |
|---|---|---|
| 1. Connectors, Crimps and Terminals Failure Repair Costs*,** | 5.9 | 8.9 |
| 2. Conductor/Failure Repair Costs*** | .1 | .1 |
| Subtotal | 1.0 | 8.8 |
| +15% for Material | .4 | .4 |
| TOTAL | 6.9 | 9.2 |

*Determined from failure rate in reliability analysis section
**Assuming a cost of $100/manhour for labor and overhead
***Does not include costs of methods and tooling development

E.12 Medium Ampacity Flat Cable Maintenance Costs/$10^5$ Flight Hours (Option 2, In Place Repair)

| | Item | Cost, Dollars Metal A/C | Composite A/C |
|---|---|---|---|
| 1. | Connectors, Crimps and Terminals Failure Repair Costs*,** | 3.7 | 5.3 |
| 2. | Conductor/Failure Repair Costs*** | .1 | .1 |
| | Subtotal | 3.8 | 5.4 |
| | +15% for Material | .6 | .3 |
| | TOTAL | 4.4 | 5.7 |

*Determined from failure rate in reliability analysis section
**Assuming a cost of $100/manhour for labor and overhead
***Does not include costs of methods and tooling development

## E.13 Sample Calculations for Maintenance Costs

a. Maintenance costs due to connectors

$\lambda_1$ = Connector Failures/$10^5$ hours

$$\text{Cost} = (\lambda_1)(3.61\ \frac{\text{Hrs}}{\text{Failure}})\ (\frac{100.0\$}{\text{Hr}})$$

b. Maintenance costs due to wires

$\lambda_2$ = Wire failures/$10^5$ hours

$$\text{Costs} = (.81)(\lambda_2)(2.0\ \frac{\text{Hrs}}{\text{Failure}}) +$$

$$(.19)(\lambda_2)(\text{Repair Time Estimate})\ \ (100.0\$/\text{Hr})$$

b.1 Flat Cable Harness Costs

$$\text{Costs} = (.19)(\lambda_2)(\text{Procurement + Buildup Costs})$$

# APPENDIX F

# HARNESS COST DATA

TABLE F.1

PRODUCTION EQUIPMENT COSTS

| | | Qty. | Cost |
|---|---|---|---|
| 1. | Cut & Code Equipment | | |
| | a. Conrac modification for flat cable | 1 | 20,000 |
| | b. Hand cutters @ 250 each | 10 | 2,500 |
| 2. | Stripper Equipment | | |
| | a. Automatic Abrasion Stripper | 2 | 16,000* |
| 3. | Crimper Equipment | | |
| | a. Power flat cable crimper | 4 | 20,000 |
| | b. Manual crimpers @ 250 each | 25 | 6,250 |
| 4. | Form Boards/Tie Tables | | |
| | a. Form boards-flat cable | 25 | 6,250 |
| | b. Tie tables | 3 | 3,000 |
| 5. | Sleeving Printer Equipment | | |
| | a. Flat cable modifications | 1 | 10,000 |
| 6. | Shielding Equipment | | |
| | a. Foil wrap machine | 1 | 13,000 |
| | b. Tape wrap machine | 1 | 10,000 |
| 7. | Miscellaneous Equipment | | |
| | a. Contact insert/extract tools | 10 | 3,000 |
| 8. | Potting Equipment | | |
| | a. Fixtures & Molds | 4 | 3,000 |
| | b. Test benches | 1 | 5,000 |
| 9. | Materials Handling Equipment | | |
| | a. Shelving | 1 | 5,000 |
| | b. Part Carts & Trays | 8 | 4,000 |
| | | | $145,000 |

*Stripper may not be required if insulation displacement terminations are developed.

TABLE F.2

PRODUCTION FACILITIES COST

Production Set-Up Facilities Options

1. Expansion of an existing production facility into adjacent unused areas of 3000 sq. ft.

| | | | |
|---|---|---|---|
| a. | Refurbish cost with air conditioning | = | $180,000 |
| b. | Special electrical | = | 9,000 |
| c. | Air hook-ups | = | 36,000 |
| d. | Exhaust hook-up | = | 4,000 |
| e. | Equipment installation | = | |
| f. | Miscellaneous | = | |
| | Approx. Total | = | $230,000 |

TABLE F.3

PRODUCTION TRAINING COST

<u>Contractor Training</u>

A projection of training requirements for the size of production facility and for the two proposed courses is tabulated below:

| Personnel | 24 hour | 16 hour |
|---|---|---|
| Manufacturing (hourly) | 100 | 10 |
| Quality Control | 10 | 10 |
| Engineering | - | 25 |
| Supervision | 12 | 15 |
| TOTAL | 122 | 60 |

The above personnel and course requirements yield the following:

1. Approximate number of 24 hour classes - 12 classes
2. Approximate number of 16 hour classes - 6 classes
3. Total classroom hours - 384 hours
4. Total student hours - 3888 hours
5. Course development hours
   a. Eight hours per course hour for 16 hour course 8 x 16 - 128 hours
   b. Four hours per course hour for 24 hour course 4 x 24 - 96 hours
   c. Instructor preparation 8 x 16 - 128 hours
   d. Illustrations 26 x 6 - 156 hours
6. Course maintenance

   Course length x 2 24 x 2 - 48 hours
   16 x 2 - 32 hours

Course Development Manhour Cost Goal 588 hours

Course Development Dollar Cost Goal $24,431

TABLE F.4

MANUFACTURING PROCESS FLOW TIMES (MINUTES)

RUN - High Ampacity Run (W0294)

| Item | Round Wire Metal | Round Wire Composite | Flat Cable Metal | Flat Cable Composite |
|---|---|---|---|---|
| 1. Wire measure, cut and code | 10 | 20 | 10 | 20 |
| 2. Sleeving and shielding cut | 5 | 5 | 5 | 5 |
| 3. Cable ends strip* | 2 | 4 | 3 | 6 |
| 4. Install shielding | 5 | 5 | 15 | 15 |
| 5. Install sleeving | 1 | 1 | 1 | 1 |
| 6. Form board layout | 10 | 15 | 10 | 15 |
| 7. Terminate firewall connector | 10 | 15 | 10 | 15 |
| 8. Terminate shielding and sleeving at connector | 10 | 10 | 10 | 10 |
| 9. Terminate cables in terminals | 5 | 10 | 5 | 10 |
| 10. Terminate sleeving and shielding | 10 | 10 | 10 | 10 |
| 11. Labels/patches/tape | 10 | 10 | 10 | 10 |
| 12. Test | 10 | 15 | 10 | 15 |
| 13. Pack and ship | 10 | 10 | 10 | 10 |
| Total | 98 | 130 | 109 | 142 |

*May be eliminated with insulation displacement terminations

TABLE F.5

MANUFACTURING PROCESS FLOW TIMES (MINUTES)

RUN - High Ampacity (W0322)

| Item | Round Wire Metal | Round Wire Composite | Flat Cable Metal | Flat Cable Composite |
|---|---|---|---|---|
| 1. Wire measure, cut and code | 10 | 20 | 10 | 20 |
| 2. Sleeving and shielding cut | 5 | 5 | 5 | 5 |
| 3. Cable ends strip* | 2 | 4 | 3 | 6 |
| 4. Install shielding | 7 | 7 | 15 | 15 |
| 5. Slide sleeving and pressure bulkhead feedthru | 1 | 1 | 1 | 1 |
| 6. Form board layout | 10 | 15 | 10 | 15 |
| 7. Potting of bulkhead feedthru | 20 | 20 | 20 | 20 |
| 8. Terminate shield at feedthry | 10 | 10 | 10 | 10 |
| 9. Terminate sleeving at feedthru | 2 | 2 | 2 | 2 |
| 10. Splice copper to aluminum | 8 | 16 | 5 | 8 |
| 11. Terminate firewall connector | 10 | 15 | 10 | 15 |
| 12. Terminate sleeving and shielding | 10 | 10 | 10 | 10 |
| 13. Terminate cables in terminals | 5 | 10 | 5 | 10 |
| 14. Labels/patches/tape | 10 | 10 | 10 | 10 |
| 15. Test | 10 | 15 | 10 | 15 |
| 16. Pack and ship | 10 | 10 | 10 | 10 |
| Total | 130 | 170 | 136 | 172 |

*May be eliminated with insulation displacement terminations

TABLE F.6

MANUFACTURING PROCESS FLOW TIMES (MINUTES)

RUN - Medium Ampacity (W0844)

| Item | Round Wire Metal | Round Wire Composite | Flat Cable Metal | Flat Cable Composite |
|---|---|---|---|---|
| 1. Wire measure, cut and code | 10 | 20 | 10 | 10 |
| 2. Sleeving and shielding cut | 5 | 5 | 5 | 5 |
| 3. Cable ends strip* | 2 | 4 | 3 | 6 |
| 4. Install shielding | 5 | 5 | 15 | 5 |
| 5. Slide on pressure bulkhead feedthru fitting | 1 | 1 | 1 | 1 |
| 6. Form board layout | 10 | 15 | 10 | 15 |
| 7. Potting of bulkhead feedthru | 20 | 20 | 20 | 20 |
| 8. Terminate shielding at feedthru | 10 | 10 | 10 | 10 |
| 9. Terminate sleeving at feedthru | 2 | 2 | 2 | 2 |
| 10 Terminate cable | 5 | 10 | 5 | 10 |
| 11. Terminate shielding and sleeving | 12 | 12 | 12 | 12 |
| 12. Labels/patches/tape | 10 | 10 | 10 | 10 |
| 13. Test | 10 | 15 | 10 | 15 |
| 14. Pack and ship | 10 | 10 | 10 | 10 |
| Total | 112 | 139 | 122 | 151 |

*May be eliminated with insulation displacement terminations

TABLE F.7

MANUFACTURING PROCESS FLOW TIMES (MINUTES)

RUN LOW 1 AMPACITY (W2443)

| ITEM | ROUND WIRE | | FLAT CABLE | |
|---|---|---|---|---|
| | METAL | COMPOSITE | METAL | COMPOSITE |
| 1. Wire Measure, Cut and Code | 20 | 20 | 20 | 20 |
| 2. Cable Ends Strip* | 4 | 4 | 6 | 6 |
| 3. First End Terminals | 10 | 10 | 10 | 10 |
| 4. Form Board Layout | 15 | 15 | 20 | 20 |
| 5. Cable Ends Strip | 4 | 4 | 6 | 6 |
| 6. Second End Terminals | 10 | 10 | 10 | 10 |
| 7. Labels/Patches/Tape | 10 | 10 | 10 | 10 |
| 8. Test | 15 | 15 | 15 | 15 |
| 9. Pack and Ship | 10 | 10 | 10 | 10 |
| TOTAL | 98 | 98 | 107 | 107 |

*May Be Eliminated with Insulation Displacement Terminations

TABLE F.8

MANUFACTURING PROCESS FLOW TIMES (MINUTES)

RUN LOW 2 AMPACITY 9W0708)

| ITEM | ROUND WIRE | | FLAT CABLE | |
|---|---|---|---|---|
| | METAL | COMPOSITE | METAL | COMPOSITE |
| 1. Wire Measure Cut and Code | 10 | 20 | 10 | 20 |
| 2. Cable End Strip* | 2 | 4 | 3 | 6 |
| 3. First End Terminals | 5 | 10 | 5 | 10 |
| 4. Formboard Layout | 10 | 15 | 10 | 15 |
| 5. Cable End Strip | 2 | 4 | 3 | 6 |
| 6. Second End Terminals | 5 | 10 | 5 | 10 |
| 7. Labels/Patches/Tape | 10 | 10 | 10 | 10 |
| 8. Test | 10 | 15 | 10 | 15 |
| 9. Pack and Ship | 10 | 10 | 10 | 10 |
| TOTAL | 64 | 98 | 66 | 102 |

*May Be Eliminated With Insulation Displacement Terminations

TABLE F.9

MANUFACTURING PROCESS FLOW TIMES (MINUTES)

INSTALLATION TIME

RUN HIGH AMPACITY

| ITEM | ROUND WIRE | | FLAT CABLE | |
|---|---|---|---|---|
| | METAL | COMPOSITE | METAL | COMPOSITE |
| Wing Operations (W0322) | | | | |
| 1. Feed Cable Thru Bulkhead | 10 | 11 | 10 | 12 |
| 2. Route and Bend Cable | 10 | 12 | 15 | 20 |
| 3. Attach Clamps | 15 | 20 | 15 | 20 |
| 4. Ground Shields | 5 | 5 | 5 | 5 |
| 5. Terminate Braid | 2 | 2 | 2 | 2 |
| 6. Mount Connector (Firewall) | 5 | 5 | 5 | 5 |
| 7. Mount Potting Seal | 5 | 5 | 5 | 5 |
| Body Operations (W0322) | | | | |
| 1. Route and Bend Cable | 15 | 20 | 20 | 25 |
| 2. Attach Clamps | 5 | 10 | 5 | 10 |
| 3. Mount Terminal Block | -- | -- | 5 | 7 |
| 4. Fasten Terminals | 5 | 7 | 5 | 7 |
| Engine Operations (W0294) | | | | |
| 1. Route and Bend Cable | 15 | 20 | 20 | 25 |
| 2. Attach Clamps | 5 | 10 | 5 | 10 |
| 3. Mount Terminal Block | -- | -- | 5 | 7 |
| 4. Fasten Terminals | 5 | 7 | 5 | 7 |
| 5. Ground Shield | 5 | 5 | 5 | 5 |
| 6. Terminate Sleeving | 2 | 2 | 2 | 2 |
| 7. Ground Generator | 5 | -- | 5 | -- |
| 8. Mate Connector (Firewall) | 0 | 0 | 0 | 0 |
| TOTAL | 114 | 141 | 139 | 174 |

TABLE F.10

MANUFACTURING PROCESS FLOW TIMES (MINUTES)

INSTALLATION TIME

RUN MEDIUM AMPACITY

| ITEM | ROUND WIRE METAL | ROUND WIRE COMPOSITE | FLAT CABLE METAL | FLAT CABLE COMPOSITE |
|---|---|---|---|---|
| Body Operations (W0844) | | | | |
| 1. Feed Cable Thru Bulkhead | 10 | 11 | 10 | 12 |
| 2. Route and Bend Cable | 10 | 12 | 15 | 20 |
| 3. Attach Clamps | 15 | 20 | 15 | 20 |
| 4. Feed Cable Thru Floor | 3 | 4 | 3 | 5 |
| Wheel Well Operations (W0844) | | | | |
| 1. Route and Bend Cable | 7 | 7 | 10 | 10 |
| 2. Attach Clamps | 1 | 1 | 1 | 1 |
| 3. Ground Shield | 2 | 2 | 2 | 2 |
| 4. Terminate Braid | 1 | 1 | 1 | 1 |
| 5. Mount Potting Seal | 5 | 5 | 5 | 5 |
| 6. Mate Connector | 0 | 0 | 0 | 0 |
| 7. Mount Terminal Block | -- | -- | 5 | 7 |
| 8. Fasten Terminals | -- | -- | 3 | 4 |
| Equipment Bay Operations (W0844) | | | | |
| 1. Route and Bend Cable | 10 | 12 | 15 | 20 |
| 2. Attach Clamps | 1 | 1 | 1 | 1 |
| 3. Mount Terminal Block | -- | -- | 5 | 7 |
| 4. Fasten Terminals | -- | -- | 3 | 4 |
| 5. Mate Connector | 0 | 0 | 0 | 0 |
| TOTAL | 65 | 76 | 94 | 119 |

TABLE F.11

MANUFACTURING PROCESS FLOW TIMES (MINUTES)
INSTALLATION TIME

RUN LOW 1 AMPACITY

| ITEM | ROUND WIRE METAL | ROUND WIRE COMPOSITE | FLAT CABLE METAL | FLAT CABLE COMPOSITE |
|---|---|---|---|---|
| Body Operations (W2343) | | | | |
| 1. Route and Bend Cable | 20 | 25 | 25 | 30 |
| 2. Attach Clamps | 15 | 20 | 15 | 20 |
| Rear Equipment Bay Operations (W2343) | | | | |
| 1. Route and Bend Cable | 5 | 7 | 10 | 12 |
| 2. Mount Terminal Block | -- | -- | 5 | 7 |
| 3. Fasten Terminals | -- | -- | 3 | 4 |
| 4. Mate Connector | 0 | 0 | 0 | 0 |
| CB Panel Operations (W2343) | | | | |
| 1. Route and Bend Cable | 5 | 7 | 10 | 12 |
| 2. Mount Terminal Block | -- | -- | 5 | 7 |
| 3. Fasten Terminals | -- | -- | 3 | 4 |
| 4. Mate Connector | 0 | 0 | 0 | 0 |
| TOTAL | 45 | 59 | 76 | 96 |

TABLE F.12

MANUFACTURING PROCESS FLOW TIMES (MINUTES)

INSTALLATION TIME

RUN LOW 2 AMPACITY

| ITEM | ROUND WIRE | | FLAT CABLE | |
|---|---|---|---|---|
| | METAL | COMPOSITE | METAL | COMPOSITE |
| **Body Operations (W0708)** | | | | |
| 1. Route and Bend Cable | 15 | 20 | 20 | 25 |
| 2. Attach Clamp | 7 | 8 | 7 | 8 |
| 3. Feed Cable Thru Floor | 2 | 2 | 3 | 3 |
| **Equipment Bay Operations (W0708)** | | | | |
| 1. Route and Bend Cable | 10 | 12 | 15 | 20 |
| 2. Attach Clamp | 2 | 2 | 2 | 2 |
| 3. Mount Terminal Block | -- | -- | 5 | 7 |
| 4. Fasten Terminals | -- | -- | 5 | 7 |
| 5. Mate Connector | 0 | 0 | 0 | 0 |
| **CB Panel Operations (W0708)** | | | | |
| 1. Route and Bend Cable | 5 | 5 | 10 | 10 |
| 2. Attach Clamps | 2 | 2 | 2 | 2 |
| 3. Mount Terminal Block | -- | -- | 5 | 7 |
| 4. Fasten Terminals | -- | -- | 5 | 7 |
| 5. Mate Connector | 0 | 0 | 0 | 0 |
| TOTAL | 43 | 51 | 86 | 98 |

TABLE F.13
COMPONENT COSTS
HIGH AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum. [illegible] | 2 | 61 | | 190.3 | New |
| | Insulated Wire-Copper-1.5" x .012" | 2 | 26 | | 33.2 | New |
| | Insulated Wire-Copper--#2 Round | 2 | .75 | | 3.9 | Spec: to BMS 13-51 Type I, Class I |
| | Sleeving | | | | | |
| | Sleeving | 79 | 79 | | 1.6 | Spec.: to BMS 13-51 Type I Nom. ID = 1.25" |
| | Shielding | | 37 | | 47.0 | New |
| | Shielding Ferrules | | | 2 | 1.5 | New |
| | Terminal Lug | | | | | |
| | Splice | | | 2 | 5.0 | Amp Termi-Foil |
| | Conntr/Backshell | | | 1 | 50.0 | New |
| | Clamp | | | 68 | 50.0 | New |
| | Press. Seal/Potting | | | 1 | 8.5 | New |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | 1 | 7.0 | New |
| | Shield Plate | | | 1 | 3.0 | New |

TOTAL COST = 431.0

TABLE F.14

COMPONENT COSTS

MEDIUM AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper- 1.4x.009" | 2 | 79 | | 193.1 | New |
| | Insulated Wire-Copper- #6 Round | 2 | .75 | | 1.8 | Spec.: to EMS 13-51 Type I, Class I |
| | Sleeving | | 9 | | 0.2 | EMS 13-52, Type I Nom ID = .75 |
| | Sleeving | | | | | |
| | Shielding | | 79 | | 22.9 | New |
| | Shielding Ferrules | | | 2 | 1.2 | New |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 1 | 40.0 | |
| | Clamp | | | 62 | 6.2 | BACC10DR6 |
| | Press. Seal/Potting | | | 1 | 6.0 | New |
| | Terminal Block | | | 2 | 12.0 | New |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | 1 | 2.5 | |

TOTAL COST = 285.9

TABLE F.15

COMPONENT COSTS

LOW-I AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper- 1.-1"x.009" | 2 | 91 | | 222.4 | New |
| | Insulated Wire-Copper- [illegible] Round | 2 | .75 | | 1.8 | Spec; BMS 13-51 |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | 91 | | 21.8 | New |
| | Shielding Ferrules | | | 2 | 1.2 | New |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 2 | 24.0 | |
| | Clamp | | | 72 | 3.6 | BACC10DR6 |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | 2 | 10.0 | New |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL COST = 294.8 3

TABLE F.16

COMPONENT COSTS

LOW-2 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper-[illegible] | 2 | 38 | | 15.3 | New |
| | Insulated Wire-Copper- #18 Round | 2 | .75 | | .2 | Spec.: to M27500-18[illegible] |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | 38 | | 3.0 | New |
| | Shielding Ferrules | | | 2 | 1.2 | New |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 2 | 24.0 | |
| | Clamp | | | 28 | 2.0 | Bacc10[illegible] |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | 2 | 8.0 | New |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL COST = 859.2

TABLE F.17

COMPONENT COSTS

HIGH AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum. [illegible] | 2 | 60 | | 229.0 | Spec.: to BMS 13-35 |
| | Insulated Wire-Copper-2 AWG | 2 | 25 | | 150.0 | Spec.: to BMS 13-51 |
| | Insulated Wire-Copper- | | | | | |
| | Sleeving | | [illegible] | | 1.6 | Spec.: to BMS 13-52 Type I Nom ID = .50 |
| | Sleeving | | | | | |
| | Shielding | | [illegible] | | [illegible] | Spec.: to BAC [illegible] P.N. -5D |
| | Shielding Ferrules | | | 2 | 1.2 | |
| | Terminal Lug | | | 4 | 1.6 | |
| | Splice | | | 2 | 1.5 | |
| | Conntr/Backshell | | | 1 | 50.0 | |
| | Clamp | | | 68 | 20.4 | BACC10EP - 15 |
| | Press. Seal/Potting | | | 1 | 7.0 | Seal PN BAC S45 Nylon |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | 1 | 5.0 | |
| | Shield Plate | | | 1 | 5.0 | |

TOTAL COST = 495.2

TABLE F.18

COMPONENT COSTS

MEDIUM AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper- [illegible] AWG | 2 | 76 | | 137.[illegible] | Spec.: to [illegible] 13-51 O.D.= .276 |
| | Insulated Wire-Copper- | | | | | |
| | Sleeving | | 9 | | [illegible].2 | Spec.: to [illegible] 13-52 Type I, Nom ID = .5[illegible] |
| | Sleeving | | | | | |
| | Shielding | | 76 | | 22.[illegible] | Spec.: to BAC 5[illegible] P.N. --[illegible] |
| | Shielding Ferrules | | | 2 | 1.2 | |
| | Terminal Lug | | | 2 | [illegible] | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 1 | [illegible] | |
| | Clamp | | | 62 | 7.[illegible] | P.N.: BACC[illegible]-16 |
| | Press. Seal/Potting | | | 1 | 6.[illegible] | Seal P.N. BAC [illegible]-FB2 Install and pot per: [illegible] |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | 1 | 2.5 | |

TOTAL COST = 267.1

TABLE F.19

COMPONENT COSTS.

LOW-1 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper- [illegible] | 2 | 90 | | 169.2 | Spec.: to BMS 13-[illegible] |
| | Insulated Wire-Copper- | | | | | |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | 90 | | 21.[illegible] | Spec.: to B[illegible] [illegible] |
| | Shielding Ferrules | | | 2 | 1.[illegible] | |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 2 | [illegible] | |
| | Clamp | | | 72 | 5.[illegible] | [illegible] BACC10DX-[illegible] |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL COST = 220.3

TABLE F.20

COMPONENT COSTS

LOW-2 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN COMPOSITE AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum. | 2 | 36 | | 11.5 | [illegible] |
| | Insulated Wire-Copper- | | | | | |
| | Insulated Wire-Copper- | | | | | |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | 36 | | [illegible] | [illegible] |
| | Shielding Ferrules | | | 2 | 1.2 | |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 2 | [illegible] | |
| | Clamp | | | 23 | [illegible] | [illegible] |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL COST = [illegible]

TABLE F.21

COMPONENT COSTS

HIGH AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum. [illegible] | 1 | 51 | | 95.2 | New |
| | Insulated Wire-Copper-[illegible] | 1 | 35 | | [illegible] | New |
| | Insulated Wire-Copper- #2 Round | 1 | .75 | | 2.0 | Spec.: to [illegible] Type I, Class I |
| | Sleeving | | 55 | | [illegible] | [illegible] Type I, Nom ID = 1.25 |
| | Sleeving | | 26 | | [illegible] | Same as above |
| | Shielding | | [illegible] | | [illegible] | New, [illegible] I or III |
| | Shielding Ferrules | | | 2 | [illegible] | New |
| | Terminal Lug | | | | | |
| | Splice | | | 1 | 2.5 | New |
| | Conntr/Backshell | | | 1 | [illegible] | |
| | Clamp | | | [illegible] | [illegible] | New |
| | Press. Seal/Potting | | | 1 | [illegible] | New |
| | Terminal Block | | | 2 | 15.0 | New |
| | RFI Stuffing Tube | | | 1 | 7.0 | New |
| | Shield Plate | | | | | |

TOTAL COST = 277.-

TABLE F.22

COMPONENT COSTS

MEDIUM AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper-[illegible] | 1 | 79 | | 46.5 | New |
| | Insulated Wire-Copper- #3 Round | 1 | .75 | | 0.7 | Spec. to: BMS 13-51 Type I, Class I |
| | Sleeving | | 9 | | 0.2 | BMS 13-52 Type I Nom ID = .75 |
| | Sleeving | | | | | |
| | Shielding | | [illegible] | | 1.7 | New [illegible] I or III |
| | Shielding Ferrules | | | 2 | 1.2 | New |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 1 | 40.0 | |
| | Clamp | | | 52 | 5.2 | P.N.: BACC10DR6 |
| | Press. Seal/Potting | | | 1 | 6.0 | New |
| | Terminal Block | | | 2 | 12.0 | New |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL COST = 165.5

TABLE F.23
COMPONENT COSTS
LOW-1 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper-1,-1 x .009 | 2 | 91 | | 111.2 | New |
| | Insulated Wire-Copper- #3 Round | 2 | .75 | | 0.7 | Spec. to: EMS 13-51 Type I, Class I |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | | | | |
| | Shielding Ferrules | | | | | |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 2 | 2[illegible] | |
| | Clamp | | | 72 | 3.6 | P.N.: BACC10DR6 |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | 2 | 10.0 | New |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL COST = 1[illegible]9.5

TABLE F.24

COMPONENT COSTS

LOW-2 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC FLAT CABLE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper-[illegible] | 1 | [illegible] | | [illegible] | NEW |
| | Insulated Wire-Copper-[illegible] AWG | 1 | [illegible] | | [illegible] | [illegible] |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | | | | |
| | Shielding Ferrules | | | | | |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 1 | [illegible] | |
| | Clamp | | | 25 | 2.0 | BACC10DR6 |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | 2 | 8.0 | New |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL COST = 350.0

TABLE F.25

COMPONENT COSTS

HIGH AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum. [illegible] | 1 | 60 | | 11[illegible].0 | EMS 15-55 |
| | Insulated Wire-Copper-#2 [illegible] | 1 | [illegible] | | 55.[illegible] | Spec.: to EMS 15-51 Type I, Class I |
| | Insulated Wire-Copper- | | | | | |
| | Sleeving | | -- | | 1.5 | Spec.: to EMS 15-51 Type I NOM ID = 0.50 |
| | Sleeving | | | | | |
| | Shielding | | -- | | 11.5 | BAC5108-4[illegible] |
| | Shielding Ferrules | | | 2 | 1.0 | |
| | Terminal Lug | | | 2 | 0.8 | |
| | Splice | | | 1 | 0.8 | |
| | Conntr/Backshell | | | 1 | 50.0 | |
| | Clamp | | | 60 | 20.4 | BACC10EP-8 |
| | Press. Seal/Potting | | | 1 | 6.0 | BAC5-531 |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | [illegible] | 4.0 | |
| | Shield Plate | | | | | |

TOTAL COST = $256.0

TABLE F.26

COMPONENT COSTS

MEDIUM AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper-#6 [illegible] | 1 | 76 | | 93.5 | Spec.: to BMS 13-51 |
| | Insulated Wire-Copper- | | | | | |
| | Sleeving | | 9 | | 0.2 | Spec.: to BMS 13-52 Type I, Nom ID = 0.25 |
| | Sleeving | | | | | |
| | Shielding | | [illegible] | | [illegible] | Spec.: to B[illegible] [illegible] |
| | Shielding Ferrules | | | 2 | 1.0 | |
| | Terminal Lug | | | 1 | 0.2 | |
| | Splice | | | | | |
| | Conntr/Backshell | | | 1 | 40.0 | |
| | Clamp | | | 62 | 3.1 | BACC16DK -5 |
| | Press. Seal/Potting | | | 1 | 5.0 | BAC 3-531 |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL COST = 1[illegible]5.7

TABLE F.27

COMPONENT COSTS

LOW-1 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270 VDC ROUND WIRE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper-[illegible] | [illegible] | [illegible] | | [illegible] | Spec.: to BMS 13-51 |
| | Insulated Wire-Copper- | | | | | |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | | | | |
| | Shielding Ferrules | | | | | |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | [illegible] | [illegible] | |
| | Clamp | | | [illegible] | [illegible] | BACC10[illegible] |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL COST = 112.2

TABLE F.28

COMPONENT COSTS

LOW-2 AMPACITY CABLE RUN, INCLUDING COMPONENTS - INSTALLED IN METAL AIRFRAME

| SYSTEM | COMPONENTS | CONDUCTOR QTY | LENGTH OF RUN-FT | QTY | COST | REMARKS |
|---|---|---|---|---|---|---|
| 270VDC ROUND WIRE | Insulated Wire-Alum. | | | | | |
| | Insulated Wire-Copper- | | | | | |
| | Insulated Wire-Copper- [illegible] | 1 | 36 | | 11.5 | Spec.: To M81381 [illegible] |
| | Sleeving | | | | | |
| | Sleeving | | | | | |
| | Shielding | | | | | |
| | Shielding Ferrules | | | | | |
| | Terminal Lug | | | | | |
| | Splice | | | | | |
| | Conntr/Backshell | | | | [illegible] | [illegible] | |
| | Clamp | | | 18 | 1.0 | [illegible] |
| | Press. Seal/Potting | | | | | |
| | Terminal Block | | | | | |
| | RFI Stuffing Tube | | | | | |
| | Shield Plate | | | | | |

TOTAL COST = 341.6

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